SECRET

13

DR. PENNEY'S DRAFT BROADCAST

Recorded: 30 October 1952

When the planning began, a lot of thought was given to deciding which type of explosion would provide information and experience of the greatest value. Purely scientific measurements are most easily made when the weapon is placed at the top of a high tower, but there were other weighty considerations. The Civil Defence authorities in this country badly needed more data about atomic explosions and, accordingly, the test was planned to get as much novel information as possible for Civil Defence. The decision was made to explode the weapon in a ship moored near land, thus simulating an explosion in a port. The ship was to be equipped as a scientific transmitting station, sending out by radio a vast number of measurements about the nuclear explosion before the equipment was destroyed. More scientific apparatus was to be placed on the land to record other phenomena such as blast, heat and radioactivity.

Many comments have been made about the shape of the cloud, and how different it was from the 'mushroom' cloud with the very high stem shown in most American pictures of atomic explosions. The great weight of the mud and water in the cloud at Monte Bello kept it from rising very far.

The experiment went according to plan and the scientific records were complete. We know what happened and we can give to the Civil Defence authorities an accurate description of their problems. As you know, the explosion threw water, mud and rock into the air and on to the nearby land, causing severe radioactive contamination, and that it was necessary to measure this contamination and to recover records in the contaminated area.

Outward Telegram from Commonwealth Relations Office

TO: U.K. HIGH COMMISSIONER IN AUSTRALIA

(SENT: 01.00 hours, 22nd October 1952)

CYPHER
IMMEDIATE

No. 848 SECRET

Prime Minister Winston Churchill's Statement to House of Commons, 23 October 1952.

HURRICANE

My immediately preceding telegram.

Following is text of Prime Minister's statement. Begins.

The object of the test was to investigate the effects of an atomic explosion in a harbour. The weapon was accordingly placed in H.M.S. "PLYM", a frigate of 1,450 tons, which was anchored in the Monte Bello Islands.

2. Conditions were favourable and care was taken to wait for southerly winds so as to avoid the possibility of any significant concentration of radio-active particles spreading over the Australian mainland.

3. Specimen structures of importance to civil defence and to the Armed Services were erected at various distances. Instruments were set up to record the effect of contamination, blast, heat flash, gamma ray flash and other factors of interest.

4. The weapon was exploded in the morning of the 3rd October.

5. Thousands of tons of water and of mud and rock from the sea bottom were thrown many thousands of feet into the air and a high tidal wave was caused. The effects of blast and radio-active contamination extended over a wide area. H.M.S. "PLYM" was vaporised except for some red hot fragments which were scattered over one of the Islands and started fires in the dry vegetation.

TOP SECRET

PRIME MINISTER

Clandestine Use of Atomic Weapons

The Chiefs of Staff have been considering the possibility that the enemy might open the next war with an atomic attack on London on the model of the Japanese attack on Pearl Harbour - without warning and before any formal declaration of hostilities. The most effective method of making such an attack would be to drop an atomic bomb from a military aircraft. If the control and reporting system were fully manned and alert in a period of tension, there would be some chance that hostile aircraft approaching this country could be intercepted and driven off. At any rate, there are no special measures, outside the normal measures of air defence, which we could take in peace-time to guard against this type of attack.

2. It is, however, possible that the enemy might use other means of surprise attack with atomic weapons. A clandestine attack could be made in either of the following ways:-

(i) A complete atomic bomb could be concealed in the hold of a merchant ship coming from the Soviet Union or a satellite country to a port in the United Kingdom:

(ii) An atomic bomb might be broken down into a number of parts and introduced into this country in about fifty small packages of moderate weight. None of these packages could be detected by instruments as containing anything dangerous or explosive, and even visual inspection of the contents of the packages would not make identification certain. These packages could be introduced either as ordinary merchandise from Soviet ships, or possibly as diplomatic freight. The bomb could subsequently be assembled in any premises with the sort of equipment usual in a small garage, provided that a small team of skilled fitters was available to do the job.

3. It is difficult at any time to take practical and effective measures against this type of danger. It would be less difficult, of course, in a period immediately before the outbreak of a war which the

public had come to regard as inevitable - the period which we call the Precautionary Stage. But the enemy might prefer to make such a move in a period of comparative calm, when he might assume that less attention would be paid to security risks of this kind.

The only possible measures which could be taken to reduce this risk are control of shipping and closer supervision of diplomatic freight.

Control of Shipping

4. For effective security against this risk all suspect shipping would have to be kept at least 5,000 yards distant from any worth-while target - e.g. from London, Liverpool, Glasgow, Southampton, Bristol and Hull. There are in theory four possible ways of doing this:-

(a) Trade Attraction. All Russian ships carrying bulk cargoes on Government account could be diverted to minor ports, by specifying that that was where the consignee desired delivery of the goods. This would be regarded as discrimination against Russian ships and would invite inconvenient reprisals. It would be expensive. And it would not cover Russian ships carrying cargo ordered on private account.

(b) Diversion by Order. The Admiralty could take power to regulate the movements of all vessels, as they had in the war under Defence Regulation 43. They could then divert all ships of any kind suspected of carrying Russian cargo to minor ports. By a liberal use of this power, the diversion could be made effective; but the discrimination against Russian and satellite shipping would be so blatant that it might well end in the complete stoppage of all trade with the Iron Curtain countries.

(c) Off-shore Discharge. All Russian, Polish and Roumanian ships approaching the major ports could be instructed to discharge their cargoes at off-shore anchorages. This method would lead to retaliation. Moreover, it is hardly practicable; for grain is the main commodity carried by Russian ships and we do not possess the floating elevators which would be necessary for off-shore discharge of grain cargoes at all major ports.

(d) Port and Transit Control. In the Precautionary Stage we propose to introduce a scheme by which all ships approaching the country would be met and escorted to determined ports and anchorages. Under this control suspect ships could be diverted away from the main target areas; but the control would only be practicable in the Precautionary Stage when there would be a much reduced volume of United Kingdom and Allied shipping, and enemy shipping would be likely to keep as far away as possible from United Kingdom ports. It would be impracticable to bring this system into force at a time of normal trade with Russia and satellite countries.

5. Any action of the kind discussed in the preceding paragraph would involve some element of open discrimination against the Soviet Union; it would invite retaliation in some form; and it would probably have serious political and economic consequences. Moreover, even if those consequences could be accepted, this type of action could not completely exclude the risk. For even, if it were possible by this type of action to keep all Russian, Polish and Roumanian ships away from the main target areas, the enemy could, if he were so minded, defeat all these precautions by chartering an innocent-looking ship of another flag and using it for a clandestine atomic attack or by placing his bomb in crated merchandise consigned to this country by a neutral vessel normally trading to a U.K. port.

Supervision of Diplomatic Freight

6. If the enemy wished to introduce an atomic bomb into this country in parts and assemble them here, as suggested in paragraph 2(ii) above, the parts would probably be consigned to the Soviet Embassy in London as diplomatic freight. A foreign Embassy has an absolute right to receive by diplomatic courier correspondence which is exempt from any examination by the territorial authorities. It has a further right to import certain things without paying Customs duty, but the territorial authorities are entitled to verify that diplomatic freight and diplomatic bags are not being abused as a method of importing things which are neither documents nor things which the Embassy has a right to import without paying Customs duty. It would therefore be permissible for us to open the Soviet diplomatic bag or to examine diplomatic freight for this purpose, provided that this were done in the presence of a member of the Soviet Embassy and that no attempt was made to open seals on any documents in envelopes. There would, however, be serious risks in doing so. We should invite immediate reprisals, which might involve widespread interference with our arrangements for supplying our own diplomatic missions behind the Iron

Curtain. In an exchange of discourtesies like this, we should normally have more to lose than to gain. Action of this kind could not fail to increase international tension. These disadvantages are certain. The gain, on the other hand, would be problematical; for we understand that, even if packages were opened and subjected to expert inspection, it could not be established with certainty that the contents were not parts of an atomic bomb.

7. Although it may be impracticable to prevent the importation of parts of an atomic bomb into this country, whether as diplomatic freight or otherwise, it is just possible that we might be able to detect the preparation for its assembly. This process would probably be directed and controlled through the Soviet Embassy in London, and it might be possible by increased vigilance to detect suspicious movements of vehicles to and from the Embassy. That is a point which we should like to examine further. It is of course by no means certain that we should be able by this means to secure, until it was too late, any positive indication that a bomb was being assembled here.

Conclusion

8. It is clear that it would be practicable for the Russians to introduce an atomic bomb into this country by clandestine methods. It is equally clear that there is no certain method of preventing them from doing so. The most that we could secure, by taking any of the measures discussed in this minute, would be to make their task more difficult. And the adoption of any of these measures would involve considerable risks and serious political and economic difficulties. This being so, it seems legitimate to ask whether the Russians would think it worth while to adopt these elaborate clandestine methods of launching an atomic attack when a military aircraft might do the job more effectively for them. An even larger question is whether the Russians would think it was worth their while to invite immediate retaliation by atomic attack against themselves so long as the advantage in numbers of atomic bombs remains overwhelmingly with the Americans.

9. The Chiefs of Staff have already arranged for an official working party (comprising representatives of the interested civil Departments) to consider means of guarding against this risk, and the possible

counter-measures discussed in this minute were all suggested in the report of this working party. The Chiefs of Staff have now asked me to arrange for further Departmental examination of these proposals and for any necessary submission to Ministers. For the reasons indicated in this minute I am very doubtful whether the increased security which might be obtained by adopting any of these measures could outweigh the very serious disadvantages, political and economic, which would be entailed. I have therefore thought it desirable to seek your guidance in the matter before asking Departments to undertake the work of assessing those disadvantages. You may like to discuss the problem with the Foreign Secretary and the Minister of Defence; but I suggest that, for the moment, it would be preferable that it should not be discussed in any wider group of Ministers.

(Signed) NORMAN BROOK

12th July, 1951

<u>Prime Minister</u>

As requested in your letter I attach a note showing the principal events leading up to the dropping of the atomic bombs at Hiroshima and Nagasaki.

I think this account answers all the questions you asked - if you want further details I will try ~~and~~ to unearth them.

CHERWELL

<u>28th January, 1953.</u>

Mr. Pitblado has sent the originals to Miss Sturdee to keep with the book pprs.

[illegible] 29/1.

EVENTS LEADING UP TO THE USE OF THE ATOMIC BOMB, 1945

On March 21, 1944, Sir John Anderson suggested that the Tube Alloys programme should be mentioned to the Service Ministers and to the other Ministers concerned but you minuted "I do not agree". Sir John Anderson was perturbed by your decision and I am fairly certain that in the spring of 1945 he made another attempt to persuade you to bring the matter to Cabinet and that I supported him. No papers bearing on this can however be found. In the event, it seems, the question was never discussed at Cabinet or in the Defence Committee.

2. In September 1944 Sir John Anderson minuted you annexing a report which included the information that a bomb (equivalent to 20,000 - 30,000 tons of T.N.T.) would "almost certainly" be ready by August 1945. On my return from America in November 1944, I gave you further details about the work they were doing and said that it was hoped a bomb would be ready some time the following summer.

3. In the winter of 1944/5 so far as I recollect I mentioned to you that some doubts had arisen about the initiation of the detonation of the plutonium bomb but that there was no anxiety about the U.235 bomb. But I well remember telling you in the spring of 1945 that I thought the successful explosion of a bomb was 90 to 95% certain but that the people actually working on it considered it 99% certain.

4. In April 1945 Lord Wilson telegraphed to Sir John Anderson that the Americans proposed to make a full scale test in the desert in July and to drop a bomb on the Japanese in August and I told you about this.

5. On May 2 Sir John Anderson minuted you that he had had some details from Lord Wilson of the American intentions for the operational use of the bomb and requested your approval of his proposal that Lord Wilson should tell General Marshall that you had been consulted and would want to be kept informed. On May 21 you agreed that Wilson should speak to Marshall "in a tactful and friendly way";

you thought that the machinery for reaching a joint decision would emerge from this talk. Discussions took place and it was agreed that in order to fulfil the Quebec Agreement the concurrence of H.M.G. should be recorded at a meeting of the Combined Policy Committee.

6. On June 29 Sir John Anderson reminded you of the American intentions about which I had told you. In this minute he requested authority to instruct our representatives to give the concurrence of H.M.G. in the decision to use the bomb against the Japanese./ You initialled this minute on July 1. On July 4 Lord Wilson formally gave the concurrence at a meeting of the C.P.C

7. A minute from Rickett to Sir John Anderson's Secretary dated July 2 reads:

"Lord Cherwell told me this evening that in initialling the Chancellor's minute of the 29th June on the Operational Use of T.A., the Prime Minister had wished it to be understood that he would expect to discuss this matter with President Truman at TERMINAL, though he was anxious that nothing should be done by us to retard the use of the T.A. weapon."

8. A report on discussions at Potsdam records:

"Mr. Stimson described the results of the recent test to the Prime Minister and the Prime Minister confirmed the agreement given by Field Marshal Wilson at a meeting of the Combined Policy Committee to the use of the weapon within the next few weeks against the Japanese."

9. It must be remembered that until the actual explosin in the desert in New Mexico there was great scepticism in military and political circles about the efficacy of the new form of explosive. Certainly nobody thought it would end the war. And in fact it is doubtful to what extent it did so. As you know it has now been proved that the Japanese asked the Russians to convey an offer accepting the Potsdam terms of unconditional surrender to the Allies on August 2. The Russians did not pass on this message. Had they done so, it might well be that the bombs on Hiroshima and Nagasaki would not have been dropped. Whether the fact that they were dropped did more than induce the Japanese to make a direct offer of surrender to the Americans is therefore questionable.

8
END

10. In retrospect it seems unlikely that the atom bombardment could have forced the Japanese to surrender before the planned invasion of the Home Islands in November 1945, had they not - unknown to us - been already at the point of collapse. For the Americans could not have dropped much more than two bombs a month for the rest of the year. But of course the Japanese did not know this.

28th January, 1953

~~TOP~~ SECRET—GUARD

Misc./P (54) 29
27th August, 1954

DEPARTMENT OF ATOMIC ENERGY

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

SCIENTIFIC DATA OBTAINED AT OPERATION HURRICANE

TOP SECRET SECTION OF DIRECTOR'S REPORT

Issued by
Ministry of Defence,
London, S.W.1.

27th August, 1954

~~TOP~~ SECRET—GUARD

DEPARTMENT OF ATOMIC ENERGY

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

(formerly of Ministry of Supply)

OPERATION HURRICANE—THE DOSE-RATE CONTOURS OF THE RESIDUAL RADIOACTIVE CONTAMINATION

(Monte Bello, Australia—October, 1952)

TOP SECRET SECTION OF DIRECTOR'S REPORT

Summary

This section of the report on scientific data obtained at Operation Hurricane gives the dose-rate contours of the residual radioactive contamination resulting from the detonation of the first British atomic weapon which was exploded under conditions representing a ship-borne attack on a port.

The main body of the report, issued separately, covers other aspects of the contamination, as well as the air blast, gamma flash, thermal radiation and under-water shock.

The results given in the present section imply that the residual contamination due to the deposited fission products provides a major contribution to the effect of a weapon detonated in this way.

Approximate estimates suggest that the area in which a median lethal dose of 400 roentgens of gamma radiation could be received may be increased by the contamination by a factor of from two to four.

7.8. The Dose-rate Contours of the Residual Radioactive Contamination

7.8.1. The numbering of this sub-section follows that of the main report in which Section 7 deals with the residual contamination.

7.8.2. From an examination of the day-to-day radiological survey measurements at various points on the different islands and by the application of the gross decay relationship given in section 7.3. of the main report, a set of dose-rate contours at 1 hour after the explosion has been constructed as shown in Fig. 7.2. These are shown dotted over the sea areas because although the dose-rates in these regions would be the same as over land immediately after fall-out, the rapid dispersal of the contamination (see section 7.6.) in the sea would soon reduce the radiation dose-rate there to a negligible quantity. The dose-rate on a ship in these regions would, of course, be the same as on land until decontamination had been effected.

It will be seen that the radiation dose-rate from deposited fission products would be very high on land near an atomic explosion in a ship.

7.8.3. The areas within the various contours and the equivalent radii are given below in comparison with radii derived from figures given in "The Effects of Atomic Weapons" for an airburst at 100 feet over land.

TABLE 7.4.

Dose-rate (r/hr) at one hour	Monte Bello Weapon: Area (Sq. Miles)	Monte Bello Weapon: Equivalent Radius (Feet)	Low Air-burst over Land. Radius (Feet)
10,000	0·62	2,350	—
6,000	0·85	2,750	200
3,000	1·12	3,150	450
2,000	1·62	3,800	525
1,000	2·65	4,850	575
600	3·2	5,350	600
400	3·7	5,750	700
200	4.8	6,500	850

Since the lethal distance from the gamma flash, corresponding to the median lethal dose of 400r, is about 4,000 feet in both cases, it appears that whereas for a low airburst over land the lethal area is not likely to be appreciably increased by the contamination, the area due to a weapon exploded under the same conditions as at Monte Bello is likely to be considerably increased by the activity of the deposited fission products.

Approximate estimates suggest that the area in which a median lethal dose of gamma radiation is received may be increased by the contamination by a factor of 2 to 4 depending on the degree of screening afforded by buildings and the time taken to get out of the contaminated area.

7.8.4. A comparison may also be made between the contamination from the Monte Bello weapon and that which would be expected on land areas near to an underwater atomic explosion such as the one at Bikini Test Baker. The areas within the 50 r/hr contour from the Monte Bello weapon and from the underwater burst at Bikini Test Baker, for which estimates are given in Figure 8.101 of "The Effects of Atomic Weapons," are about equal. Within the 400 r/hr contour the area from the Monte Bello weapon is larger by a factor of about 3 to 4 while for regions of heavier contamination the areas within its contours will apparently be even greater relative to the Bikini weapon.

7.8.5. A further radiological survey was made in November, 1953, 405 days after the explosion and the islands were found to be still highly radio-active.

Although in some places drifting sand had materially reduced the gamma radiation compared with that in places where the soil surface was held by vegetation, in general, despite some 16 inches of rain and a cyclone in early 1953, there was no apparent evidence of the accelerated decay of fission products due to weathering.

From readings taken at certain points immediately after the trial and again in November, 1953, the decay factor from 1 hour to 405 days after the explosion was found to be 200,000. By applying this factor to the various readings obtained during this second survey, gamma dose-rate contours at one hour were constructed. These were found to be very similar in shape and size to those shown in Fig. 7.2. which are based on observations made during the period immediately following the explosion.

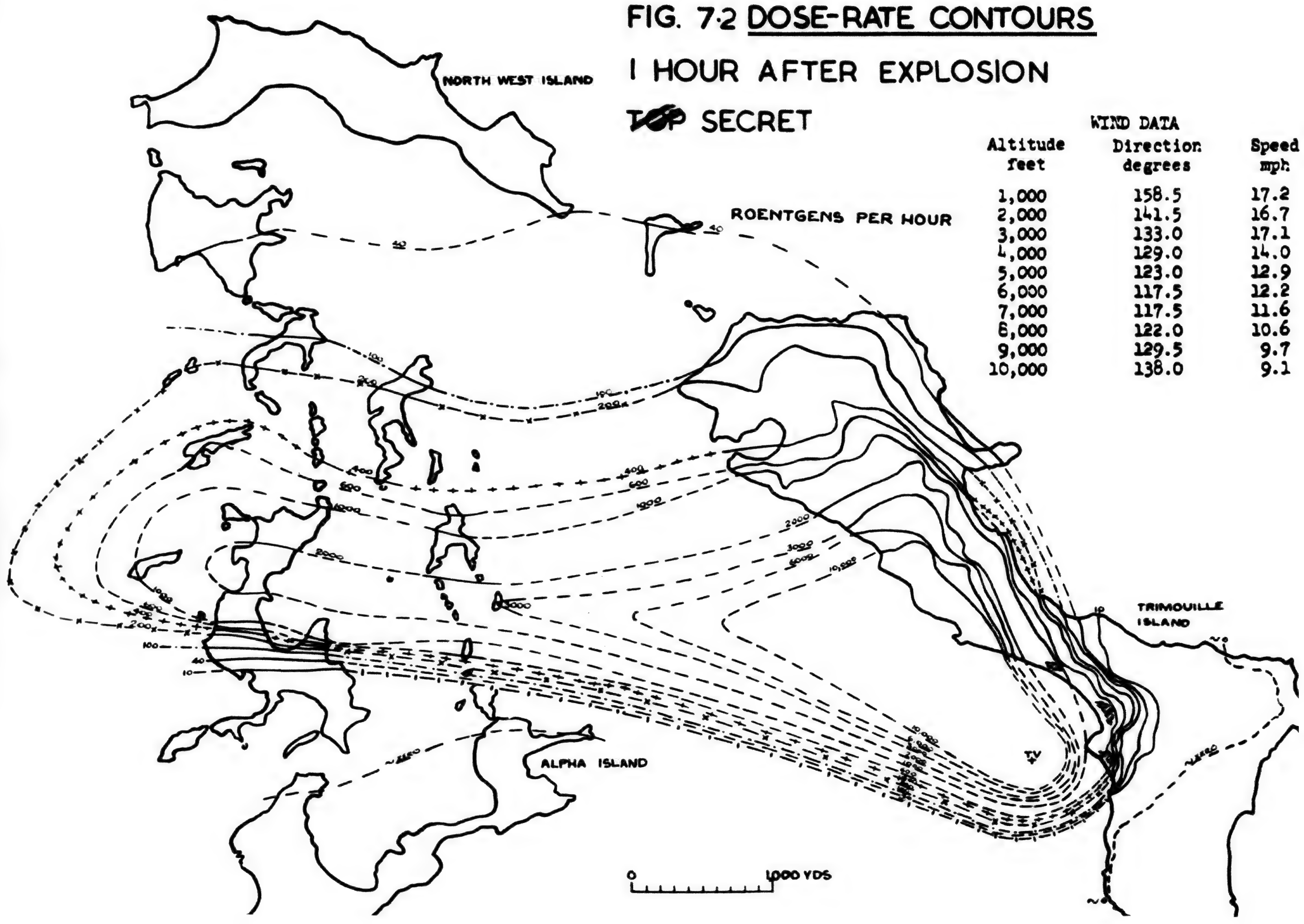
FIG. 7.2 DOSE-RATE CONTOURS

1 HOUR AFTER EXPLOSION

~~TOP~~ SECRET

WIND DATA

Altitude feet	Direction degrees	Speed mph
1,000	158.5	17.2
2,000	141.5	16.7
3,000	133.0	17.1
4,000	129.0	14.0
5,000	123.0	12.9
6,000	117.5	12.2
7,000	117.5	11.6
8,000	122.0	10.6
9,000	129.5	9.7
10,000	138.0	9.1



AWRE-T1/54 (27 AUGUST 1954)

DEPARTMENT OF ATOMIC ENERGY

ATOMIC WEAPONS RESEARCH ESTABLISHMENT
(formerly of Ministry of Supply)

SCIENTIFIC DATA OBTAINED AT OPERATION HURRICANE
(Monte Bello Islands, Australia—October, 1952)

DIRECTOR'S REPORT

Summary

This report summarises data on the external effects observed in the trial of the first British atomic weapon, which was exploded under conditions representing a ship-borne attack on a port.

Briefly, it may be said, in reviewing the general physical effects, that the air blast and gamma flash effects were comparable with those for an air burst but the thermal radiation effects were very much less. The underwater shock was much less than that from an underwater burst. Some general information on the residual contamination is given, but data on the extent of the contamination forms the subject of a separate section not generally available.

The report describes the conditions under which the trial was conducted, the measurements made of the physical phenomena produced by the detonation of the weapon, and gives brief descriptions of the results.

Information is given concerning the behaviour of Anderson shelters, of certain reinforced concrete cubicles, of a model ship's funnel, of a compartment representing a deckhouse, and various aircraft components. Data are also given for the penetration of gamma rays into slit trenches, concrete cubicles and Anderson shelters; for the effect of thermal radiation on various materials and service equipment; and for possible contamination (and decontamination) of personnel, equipment, ships and food stored in open dumps. The report also includes the results of experiments on the absorption of radio-elements by biological systems.

PART I.—BASIC SCIENTIFIC MEASUREMENTS

1. Trial Conditions and Effects Observed

1.1. The trial was carried out in the Monte Bello Islands lying about 50 miles off the North-West coast of Australia. Fig. 1.1 gives a map of these islands.

The weapon was exploded at 9·30 a.m., local time, on October 2nd, 1952, in H.M.S. *Plym*, a frigate lying in a shallow channel about 400 yards offshore from Trimouille Island. The depth of water was about 40 feet and the weapon centre was 9 feet below the water line. The conditions of burst were thus representative of a ship-borne attack on a port.

1.2. The variation of wind speed and direction was obtained by means of a balloon ascent one hour after burst. At ground level the wind was southerly (175°) with a speed of 17 knots. With increasing height it changed through east to become slightly north of east (77°) at 6,000 feet with a speed of 10 knots. The change in direction with height was then rapidly reversed so that the wind was practically due south again at 8,000 feet after which it changed gradually to about south-westerly at 12,000 feet and finally to westerly at 20,000 feet. Thus the wind was coming straight off the mainland up to about 8,000 feet after which it blew roughly parallel with the coast line. The speed decreased steadily up to 7,000 feet and then increased. The results are displayed in Fig. 1.1.

1.3. The main control centre was located at H 1 at the southern end of Hermite Island. Other key points, including A4, N4 and T4, will be referred to in connection with particular measurements.

1.4. The basic scientific measurements which were made covered all aspects which might be likely to have practical importance. One aspect, namely the thermal radiation, proved to have definitely less importance than it would have had in the case of an airburst bomb. The blast, gamma radiation and the contamination were the major effects at the observation sites.

The various measurements are considered in detail in the following pages, starting with a description of the phenomena (fireball and water column) photoghaphed from a distance immediately after the detonation of the bomb. The air blast, gamma flash, thermal radiation and contamination which reached the observation posts are then considered, followed by the underwater shock, the crater in the sea-bed and the earth movements observed on the shore of Trimouille Island.

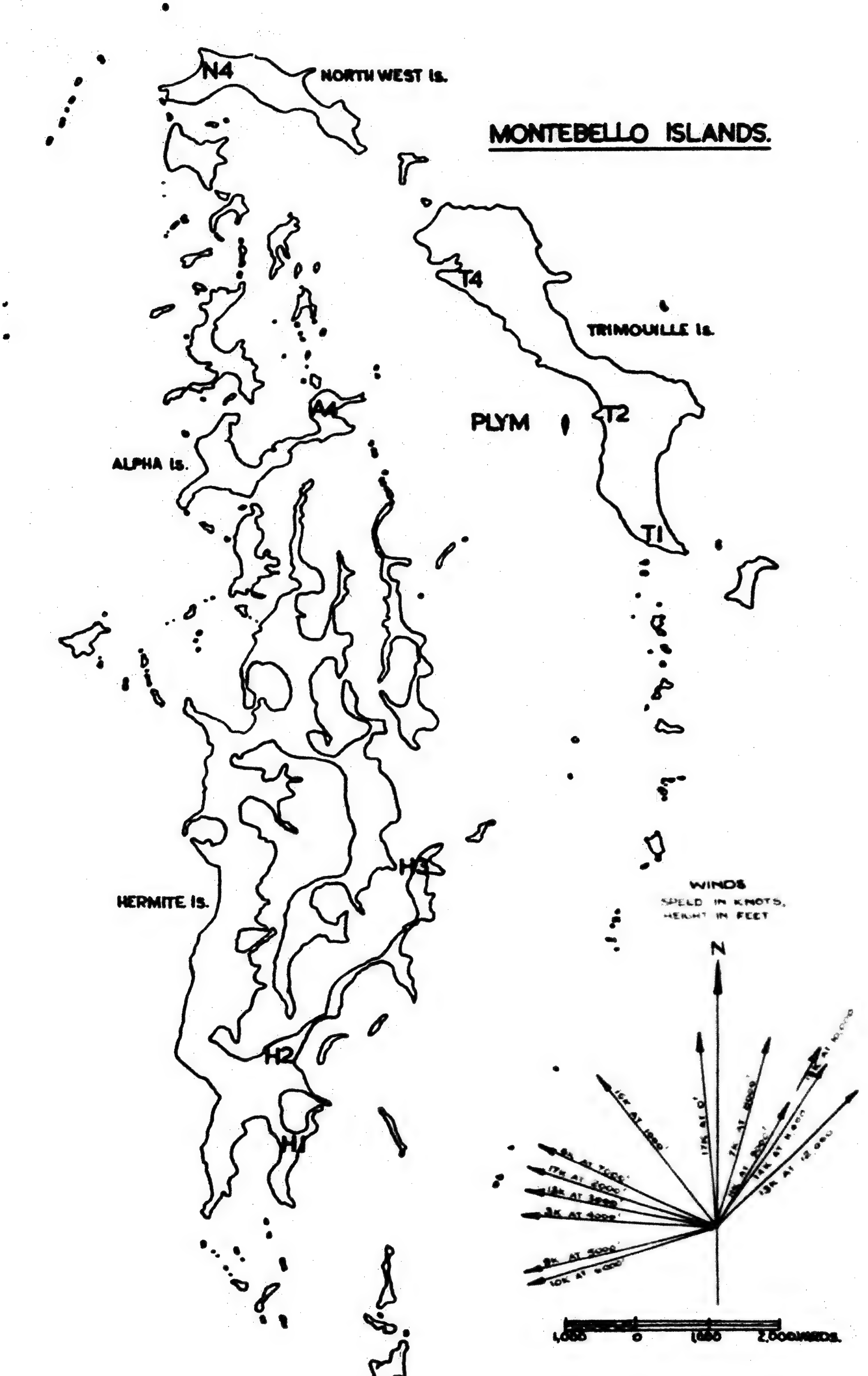

MONTEBELLO ISLANDS.
N4
NORTH WEST Is.
T4
TRIMOUILLE Is.
A4
PLYM
T2
ALPHA Is.
T1
H3
HERMITE Is.
H2
H1
WINDS
SPEED IN KNOTS,
HEIGHT IN FEET
N
17K AT 2000'
3K AT 4000'
10K AT 6000'
1,000
0
1,000
2,000 YARDS.

FIG. 1.1.

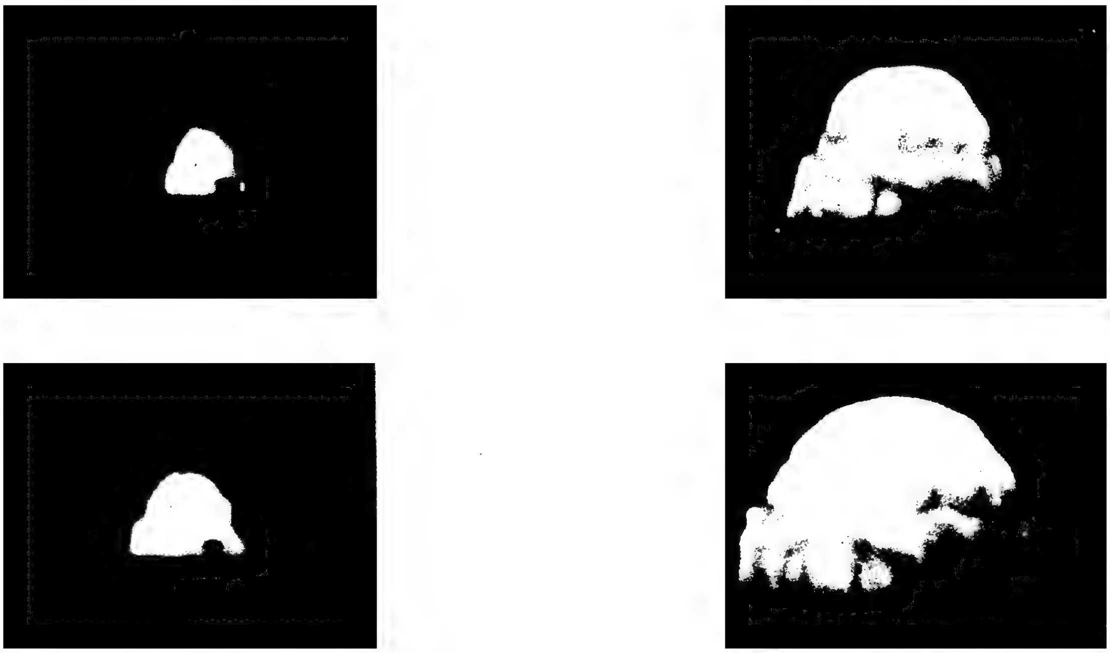
2. The Fireball

2.1. The fireball was first observed from H 1 with the Kerr cell camera at 23 microseconds after explosion as a faint segment of a circle on the water-line of *Plym*. Within the accuracy of measurement, it appeared to emerge from the point on the ship's side nearest to the weapon. Fig. 2.1 shows successive stages in the development of the fireball up to 3·75 milliseconds. In the early frames the bows of the target vessel can be seen silhouetted against a portion of the fireball which has emerged from the far side of the ship.

2.2. Fig. 2.2 shows the variation with time of the height of the top of the fireball above the weapon centre. The time t is taken from the arrival of the first gamma radiations. In the early stages, for about the first 1·5 milliseconds, this height varies approximately as $t^{\frac{1}{2}}$, after which it follows a more familiar $t^{\frac{2}{5}}$ relation up to about 100 milliseconds. The increase in the diameter of the fireball on the water-line is given graphically in Fig. 2.3. The variation of the diameter of the best fitting hemisphere fits this very closely although the fireball was far from hemispherical.

2.3. At 41 milliseconds the shock wave commenced to separate from the fireball which at this stage had a height of 650 feet and a diameter at the water-line of 1,000 feet. It eventually attained a diameter of 1,700 feet in 0·6 seconds after which it started to contract leaving an inner ball 1,400 feet in diameter after about 3½ seconds. The configuration of the fireball at these later stages was rather indistinct owing to the water present in the ball itself and thrown up from the water surface by the underwater shock. As the fireball contracted it left a dark zone which appeared brown in the colour photographs. This darkening extended into the zone behind the shock wave up to a diameter of 2,500 feet and was presumably due to the presence of nitrogen dioxide.

(Annotations to PDF report version are in this typeface)



3.75 millisec

Fig. 2.1, Kerr cell camera photos of fireball emerging from far side of ship. Bows of ship are visible as dark region in the lower right of the fireball.

FIG. 2·2 RISE OF FIRE BALL.

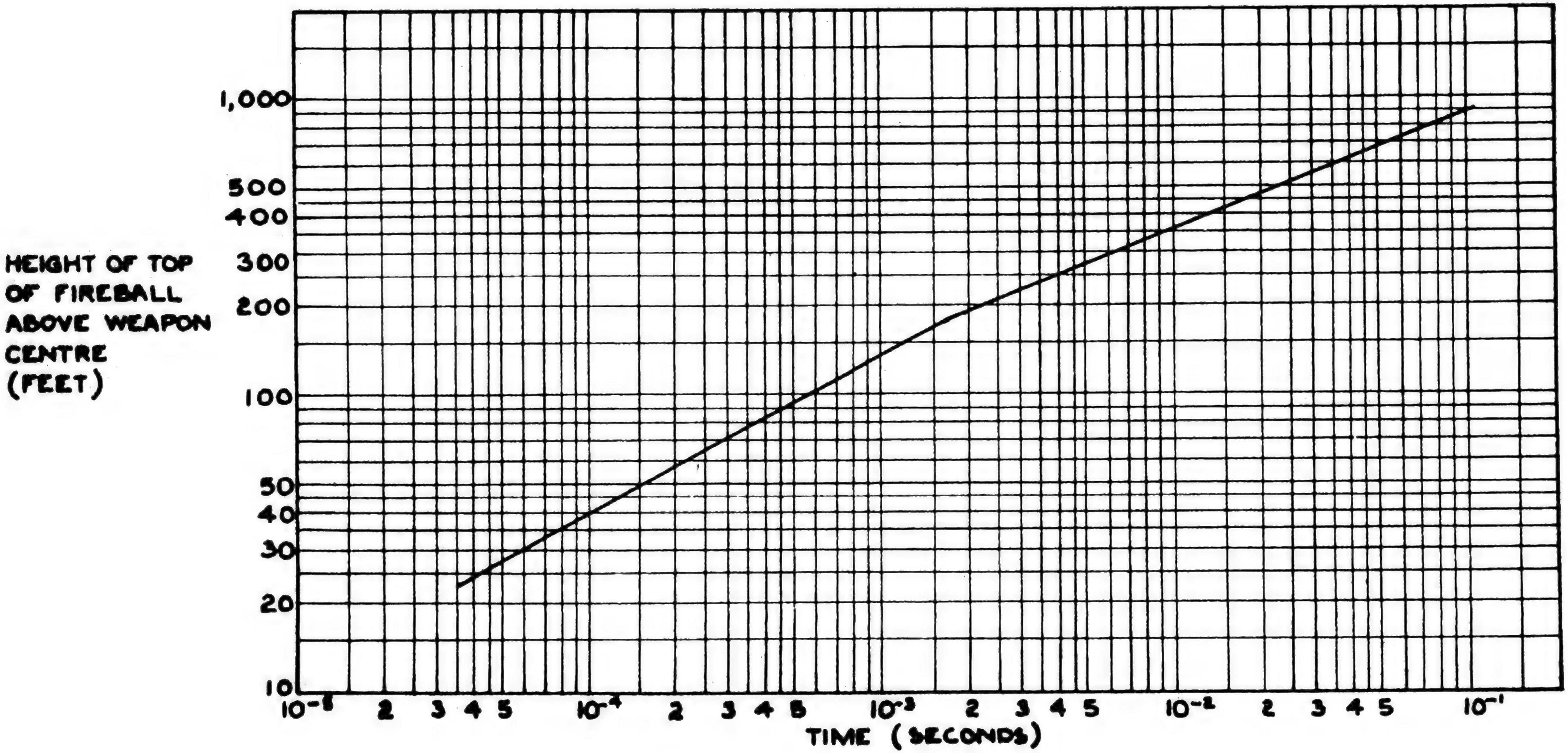
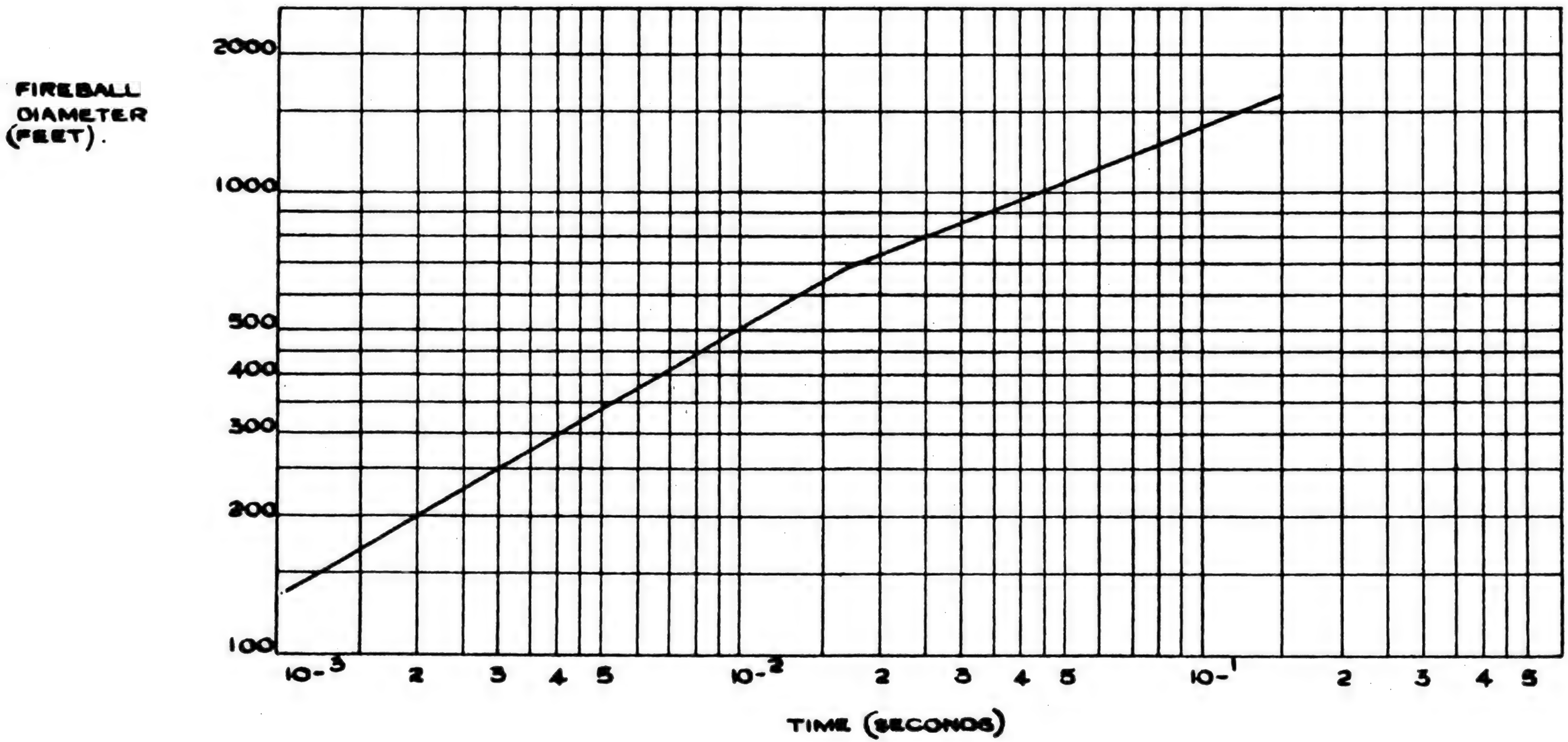


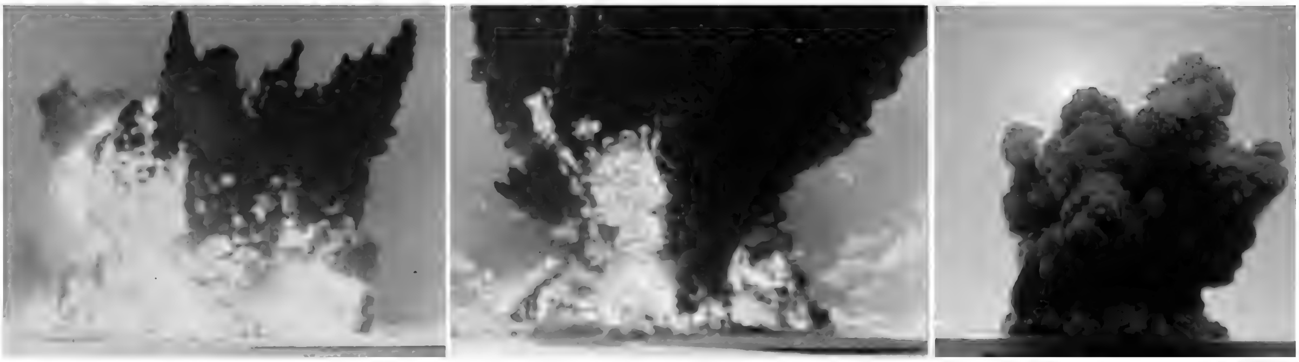
FIG. 2·3 EXPANSION OF FIREBALL ON WATERLINE.



3. The Water Column and the Cloud

3.1. Water was first observed from H 1 emerging from the fireball at an angle of about 60° to the horizontal after about 0·1 seconds, Fig. 3.1. Its height above sea level at this stage was about 650 feet and its vertical component of velocity was 350 feet per second.

Fig. 3.1, 0.1 second. Water plumes begin to emerge from fireball due to the underwater bubble expansion and cratering.



Plumes of mixed water and black ferrous oxide from ship emerge at 1-2 seconds from the top of the fireball, which cools and fades out at 3 seconds. Last photo is at 5 seconds after burst.

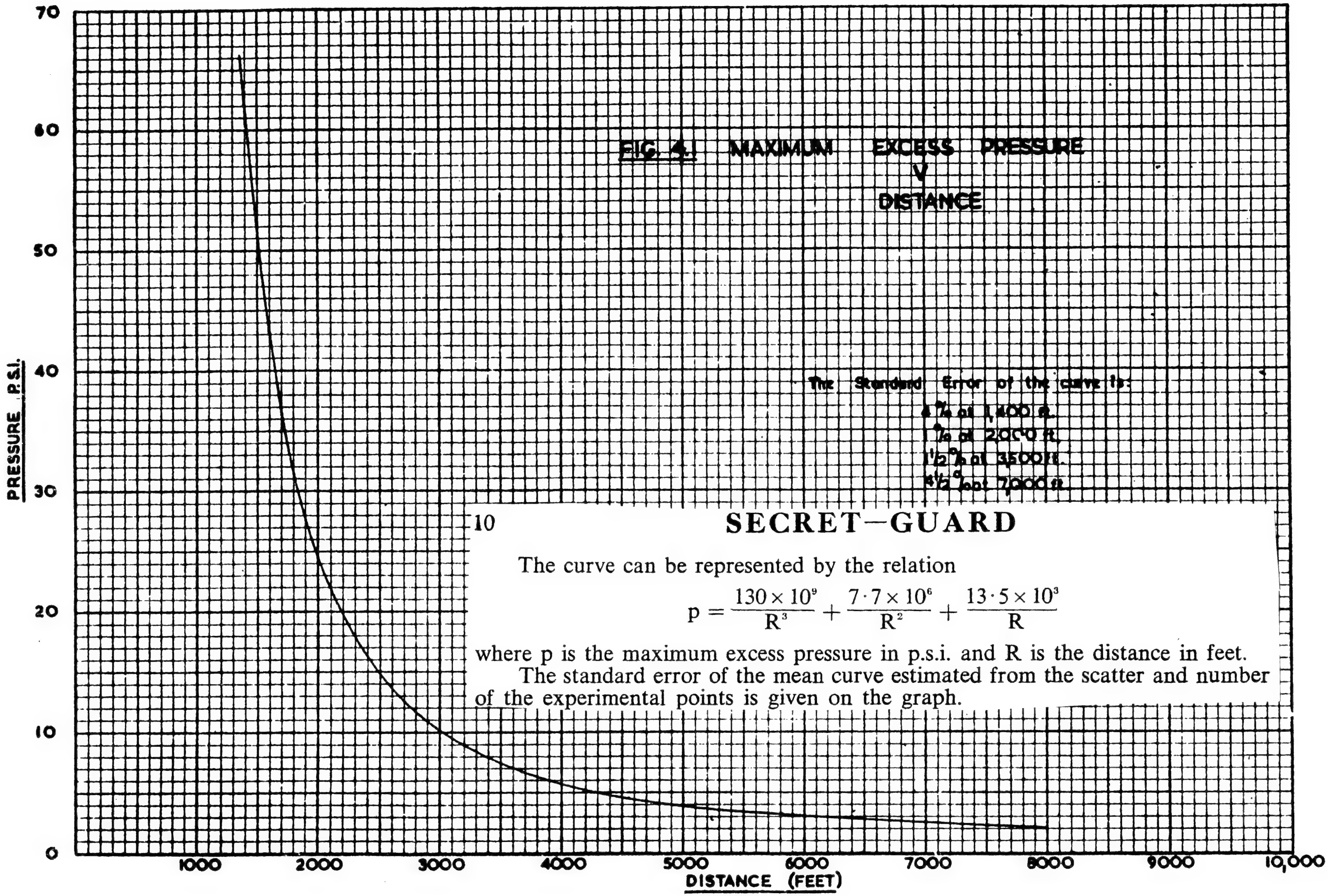
3.2. Fall-out commenced from the side of the column but this did not spread far and was probably not important. The more widespread fall-out came from the bottom of the cloud and fell with an initial velocity of about 65 feet per second reaching sea-level at about 1 minute after the explosion, Figs. 3.8 and 3.9, and continuing for at least ten minutes.

3.4. The top of the cloud rose very roughly as $t^{\frac{1}{3}}$ having a height of about 1,800 feet at 1 second and reaching a maximum of about 10,000 feet at 4 minutes, when its ascent was substantially stopped by a temperature inversion.

Fig. 3.8, cloud and base surge at 30 seconds. Water is falling from base of mushroom cloud at 65 ft/sec, and reached surface at 1 minute after burst. The base surge fallout was trivial.

Fig. 3.10, cloud and base surge at 2.5 minutes after burst.

SECRET—GUARD



The curve can be represented by the relation

$$p = \frac{130 \times 10^9}{R^3} + \frac{7 \cdot 7 \times 10^6}{R^2} + \frac{13 \cdot 5 \times 10^3}{R}$$

where p is the maximum excess pressure in p.s.i. and R is the distance in feet.

The standard error of the mean curve estimated from the scatter and number of the experimental points is given on the graph.

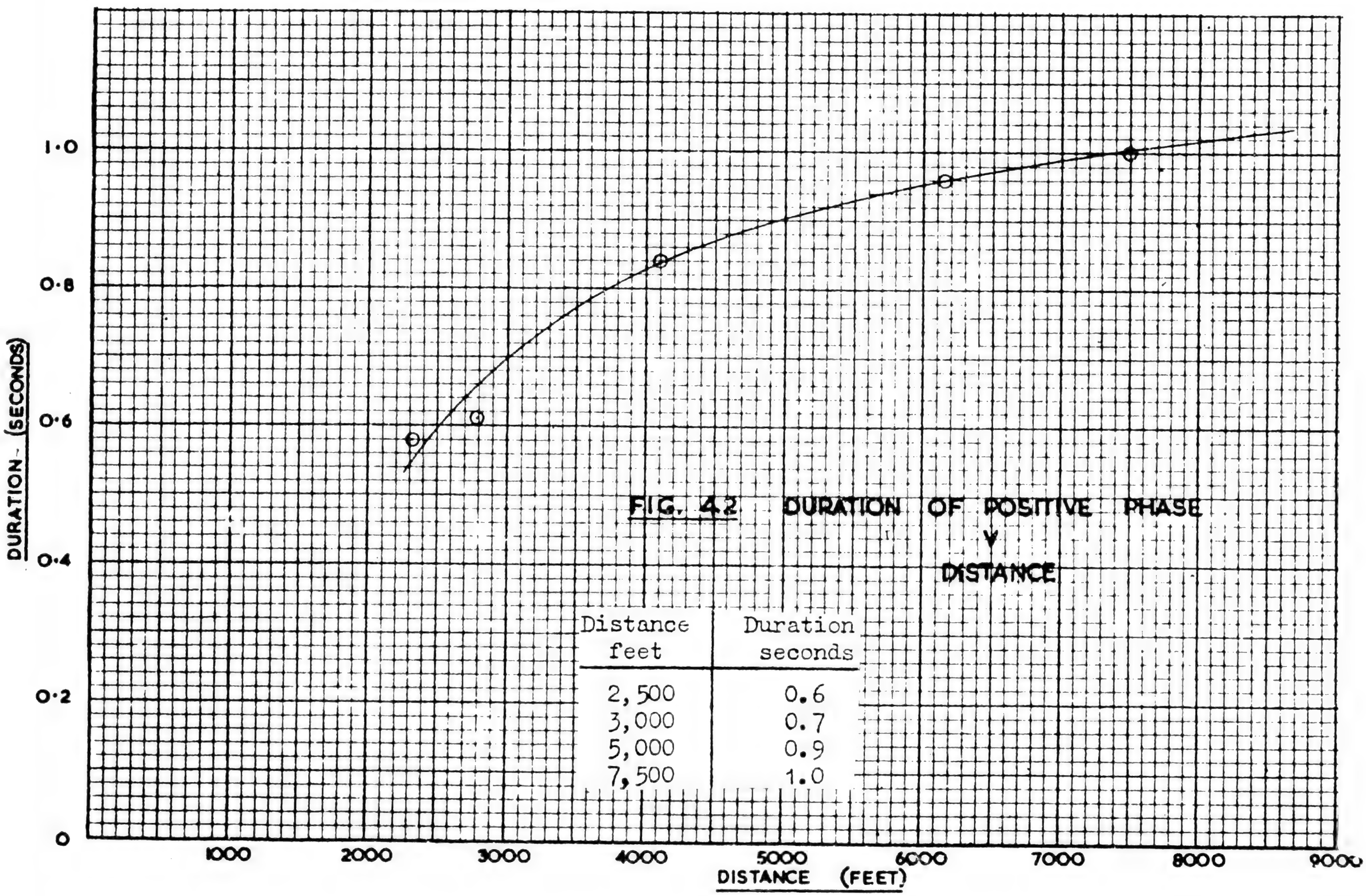


FIG. 42 DURATION OF POSITIVE PHASE v DISTANCE

Distance feet	Duration seconds
2,500	0.6
3,000	0.7
5,000	0.9
7,500	1.0

5. The Gamma Flash

5.1. The initial radiation or gamma flash comes from the rising cloud of radioactive material following the explosion and is normally confined to the first minute although most of it is received in the first second or two.

5.2. *The Variation of Gamma Flash Dose with Distance*

The total initial dose from the gamma flash was recorded by film badges placed at over 100 sites. Because of the unexpected magnitude and extent of the fall-out, many of the films were in the fall-out area and were completely blacked-out. Altogether 35 reliable readings of the dose were obtained; for these there was either a free optical path or only slight shielding, there was no fall-out and dosage readings were given by at least two different emulsions. From these readings the dosage/distance curve down shown in Fig. 5.1 was obtained. The general accuracy of the results is considered to be of the order ±10 to 15 per cent. The shielding effect of relatively small contours (of the order 30–60 ft.) was quite considerable; thus sites at equal distances from the explosion received doses that differed by as much as 50 per cent. depending on whether they were on a reverse or forward slope.

The doses received at given distances were about one half of those given for an air-burst weapon in the United States publication "The Effects of Atomic Weapons," but the distance at which a given dose was received was only about 10 per cent. less. Thus the ship's structure and the small depth of water above the point of burst did not have a very important effect in reducing the intensity of the initial radiation.

Measurements of the variations of dose-rate with time were made using flux-meters. Because of the long time-constant of the pen recorders used with them, the recording of the gamma flash was not entirely satisfactory but it was possible to use the results to obtain the approximate percentage of the total dose as a function of time. The results so obtained are given below in Table 5.1:—

Table 5.1

Time after Detonation (seconds)	*Percentage of total Dose Received*
0·05	30
0·10	50
1·0	80
10	90
60	99·5

These results indicate that about 80 per cent. of the total dose was received within one second of detonation, which is higher than the value of 50 per cent. generally quoted for an air-burst bomb and which suggests that only a small reduction in the dose received would be likely to result from evasive action.

The reason why a greater proportion of the total dose was received in the first second than would have been the case with an air-burst bomb is that the water and crater debris thrown up gave some protection after one second.

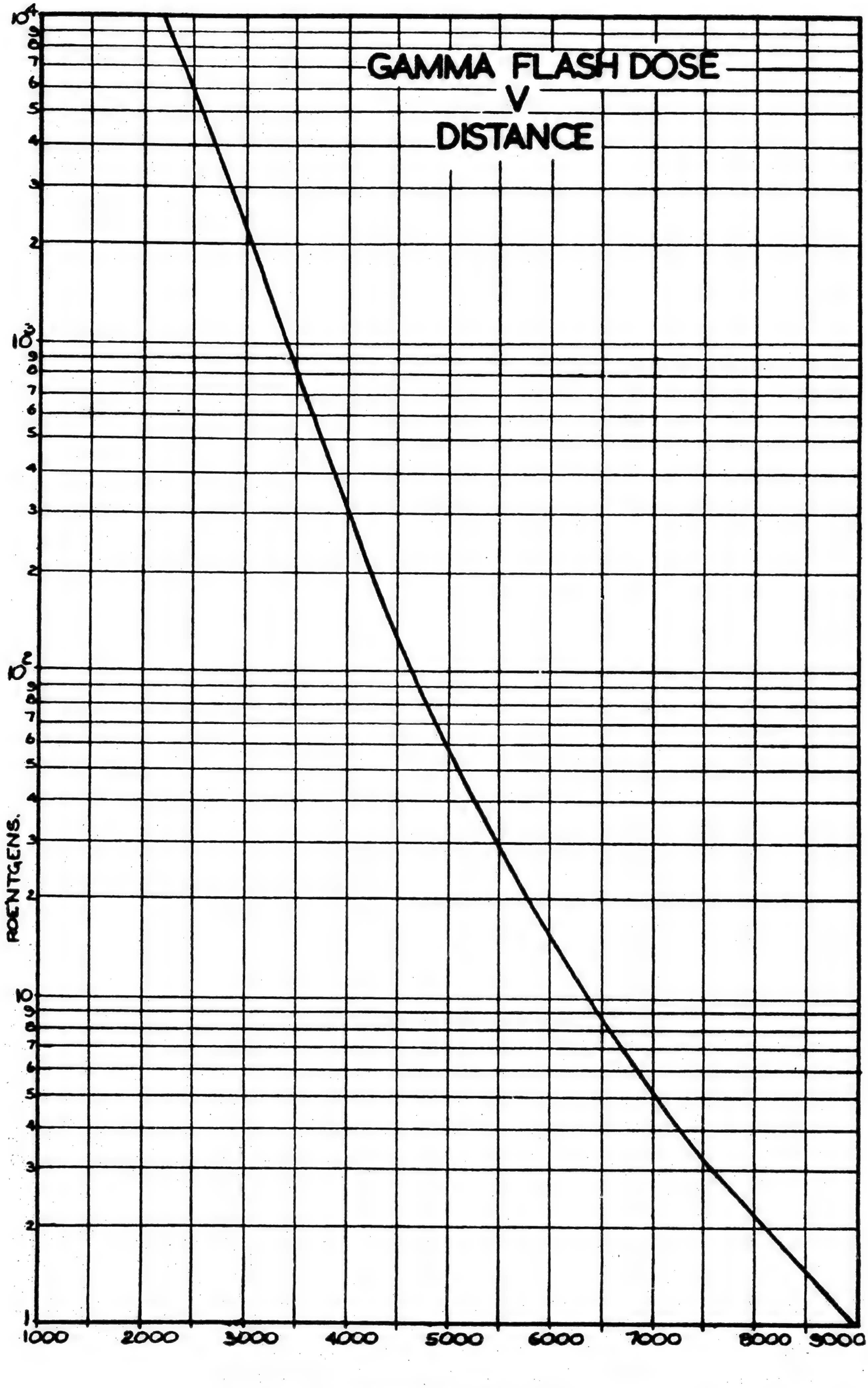

GAMMA FLASH DOSE
V
DISTANCE
ROENTGENS.
DISTANCE (FEET.)
1000
2000
3000
4000
5000
6000
7000
8000
9000

FIG. 5-1

6. Thermal Radiation

6.1. A number of methods were used to measure the total heat radiated by the fireball and the variation with time of the intensity of the radiation in a number of wave-bands and at various distances from the explosion.

6.2. *Variation of Intensity with Time*

6.2.1. Photo-electric recorders and photographic film recorders were used to obtain the variation of total intensity with time at 35,530 feet (H 1) and 10,630 feet (A4), the sun being used for calibration purposes. From these records, the curves shown in Fig. 6.1 have been derived showing the variation of the thermal radiation flux per unit area, at any distance D metres in an absorption free atmosphere. Also from these records the variation of temperature of the radiating surface has been estimated and the results are shown in Fig. 6.2.

6.2.2. Similar observations were made by staff of the Royal Naval Scientific Service using a photographic film intensity recorder designed at the Admiralty Material Laboratory. With this instrument the variation of intensity with time in nine wave-bands was recorded. The estimated total thermal output over the first 15 milliseconds of the flash in the range of wave-lengths, 3,850 A° to 6,650 A°, given by this method is in good agreement with the value derived from the experiments described in the previous paragraph.

6.2.3. The experiments referred to above show that the thermal radiation occurred in two peaks with a minimum at 25 milliseconds. In the first peak the energy was concentrated mainly in the shorter wave-lengths, whereas during the second peak it was mainly in the longer wave-length region. The total duration was quite short, about 1 second compared with 3 seconds normally quoted for an air-burst, suggesting that the water spout very quickly shielded the observation points from the heat radiation.

6.3. *Integrated Radiation Output*

6.3.1. The total thermal radiation output is of direct interest since, in general, when the rate of energy is high, as it is in the case of an atomic weapon, the damage produced is dependent largely on the total quantity of energy received.

6.3.2. In one experiment the total energy at three distances was determined from the rise in temperature of blackened copper discs exposed to the flash. From the three results obtained allowance was made for atmospheric absorption and a value of $0 \cdot 36 \times 10^{12}$ calories was derived for the point source of energy which at any distance in free space would give the same thermal intensity as the fireball. The absorption coefficient of $0 \cdot 075$ Km.$^{-1}$ corresponded to a visibility of 33 miles.

6.3.3. A second method, used by staff of the Royal Naval Scientific Service, was developed at the Admiralty Materials Laboratory and employed a photochemical actinometer. This method gave results for the total energy output per sq. cm. at 3,220 and 4,630 feet in two wave-bands in the violet and near ultra-violet which for reasons which are not yet understood, were considerably higher than those given by the other methods.

6.3.4. A number of indicators designed by the Army Operational Research Group of the War Office incorporated heat sensitive papers drawn across slits. It was intended to use these to record the variation of intensity with time but, owing to the somewhat inadequate time resolution possible with the apparatus the shape of the intensity time curve obtained is probably not significant. However, the value deduced from the records for the *total* energy received at 4,024 feet was $1 \cdot 52$ calories/cm.^{2}, which is the same as would be given at that distance in free space by a point source of $0 \cdot 31 \times 10^{12}$ calories.

6.3.5. From the observations given by the photo-electric recorders, it is estimated that the total thermal energy released to the atmosphere in the first peak, *i.e.*, in the first twenty milliseconds, was $0 \cdot 05 \times 10^{12}$ calories with an equal amount lost into the ground. The total of $0 \cdot 1 \times 10^{12}$ calories in the first twenty milliseconds may be compared with a release in free air of $0 \cdot 36 \times 10^{12}$ calories for the whole flash. The overall thermal energy released from an air-burst nominal weapon is generally quoted as $6 \cdot 7 \times 10^{12}$ calories.

$0 \cdot 36 \times 10^{12}$ Calories is $1 \cdot 8\%$ of 20 kt yield

1 Kt = 10^{12} cal.

FIG 6.1

TOTAL THERMAL ENERGY FLUX AS A FUNCTION OF TIME.

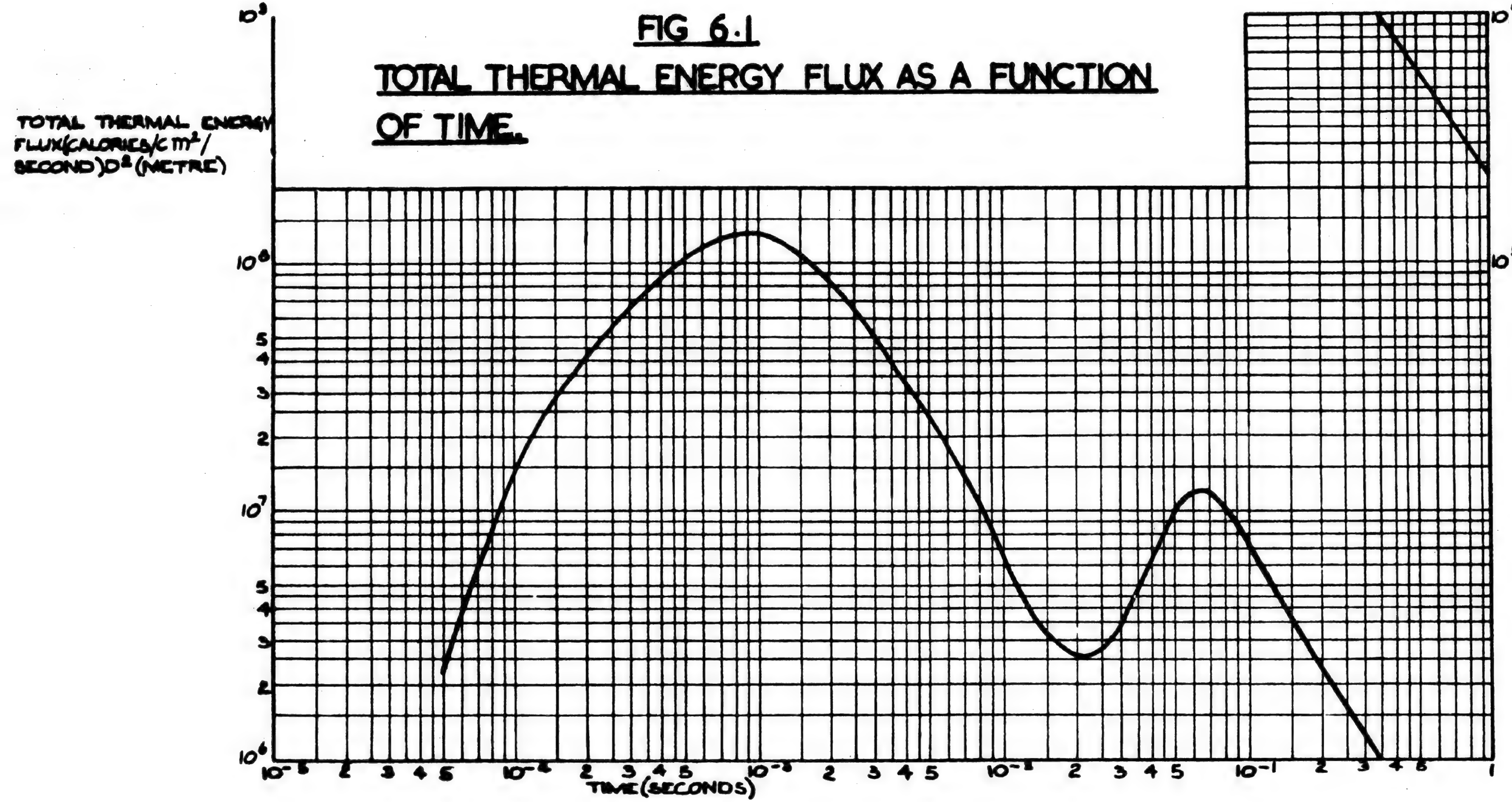
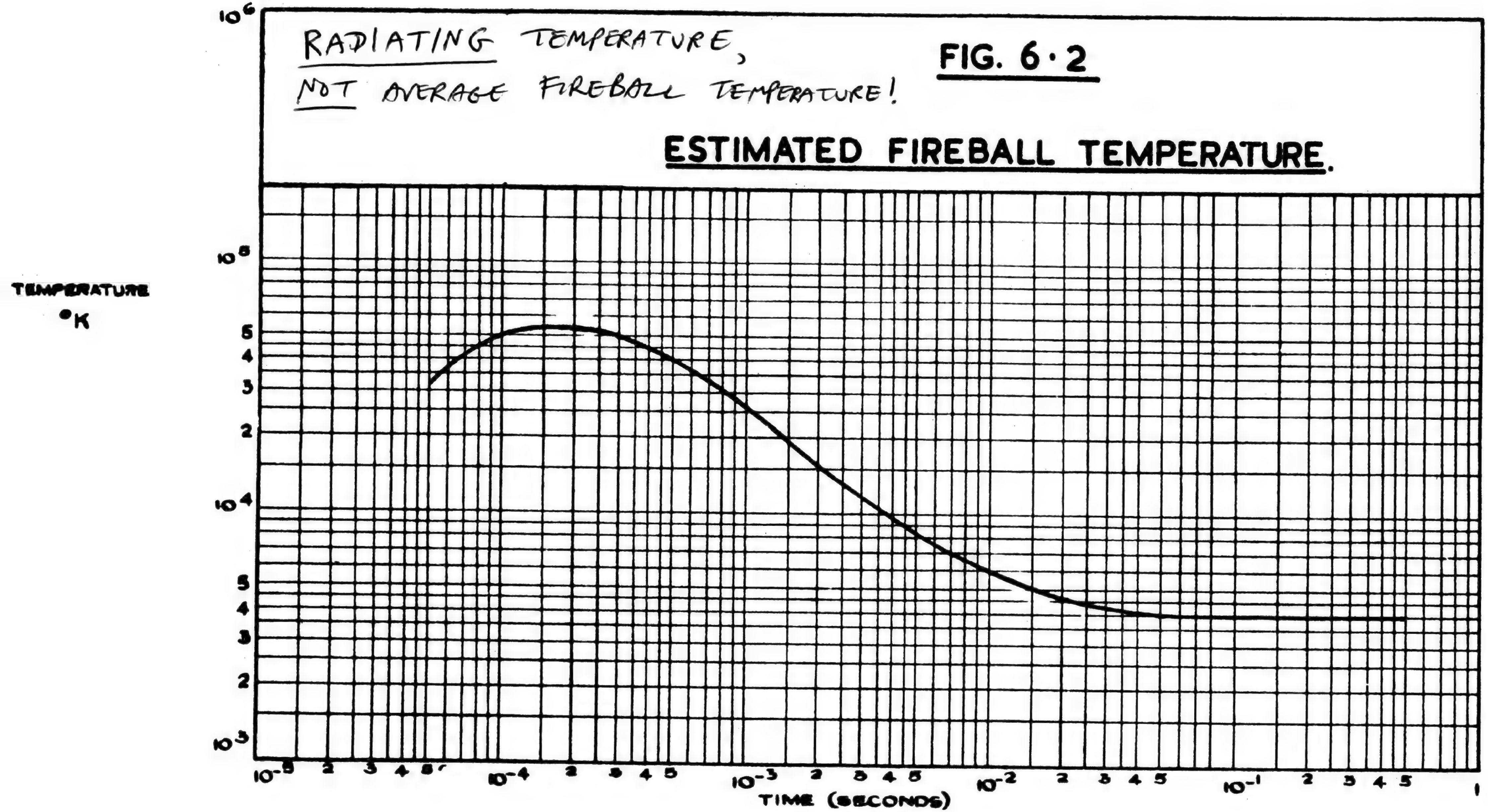


FIG. 6·2



RADIATING TEMPERATURE,
NOT AVERAGE FIREBALL TEMPERATURE!
ESTIMATED FIREBALL TEMPERATURE.
TEMPERATURE °K
10^6
10^5
5
4
3
2
10^4
5
4
3
2
10^3
10^-5
10^-4
10^-3
10^-2
10^-1
1
TIME (SECONDS)

7. The Residual Contamination

7.1. Residual contamination is due to the deposition of radioactive fission products, and lasts indefinitely with decreasing intensity.

7.2. *Dose Rates during the First Twelve Hours*

Continuous records of the dose-rate r of the gamma radiation from the residual contamination were made at various distances during the period 0 to 10 hours from the time of detonation. These were intended to give the time of arrival of the fall-out and the value of the exponent x in the relation $dr/dt = k\,t^{-x}$ over the first twelve hours.

For this purpose fluxmeters of the ionisation chamber variety were used in conjunction with pen recorders. These were protected from the effects of the blast by hermetically sealed steel casings about ¼-inch thick and were shielded from the sun by a horizontal steel plate also ¼-inch thick. It was estimated that the observed radiation doses should be increased by 25 per cent. to allow for the effect of these shields.

The time of arrival of the fall-out in the downwind areas of widespread contamination was approximately proportional to the distance from the explosion and a period of about one minute was required for each 2,500 feet of distance. This time clearly depends on the meteorological conditions obtaining at the time and is thus not of general application.

The measured decay factor varied over the fall-out area but a mean value of 1·45 is considered reasonable, *i.e.*, the dose-rate over the first twelve hours is proportional to $t^{-1.45}$.

7.3. *The Gross Decay Law up to 1000 Hours*

For later periods up to about 1000 hours dose-rate measurements were made by survey teams using portable monitors. The decay factors obtained at various points over the area were in fair agreement. Since the terrain varied from rock to very sandy areas, this agreement suggests that wind erosion was slight, perhaps merely resulting in a continual shifting of the active dust over a restricted region, and implies that the loss in intensity was due almost entirely to radioactive decay.

The dose-rate values have all been reduced to correspond to a dose of 1 roentgen per hour at H+1 (one hour after the explosion) and the results are shown graphically in Fig. 7.1. It will be seen that the results for the later times do not fit well with the results up to 12 hours and there is quite a pronounced scatter in the period 100 to 200 hours. It has been found from experiments carried out since the trial that, as the survey meters are dependent on the photon energies of the gamma rays up to 0·2 Mev, the readings given by these monitors are likely to have been too high by a factor of as much as 1·3. By reducing the dose-rates by a factor 1·3 the curve II of Fig. 7.1 is obtained which joins up with the curve for times up to 10 hours very much better.

It may be seen that:—

(i) for the first twelve hours the dose-rate varied at $t^{-1.45}$;
(ii) between 12 and 100 hours, the decay was proportional to about $t^{-1.2}$;
(iii) between 100 and 200 hours, the decay was slower and very roughly as $t^{-1.0}$;
(iv) after 200 hours, it was rapid and varied as $t^{-1.6}$.

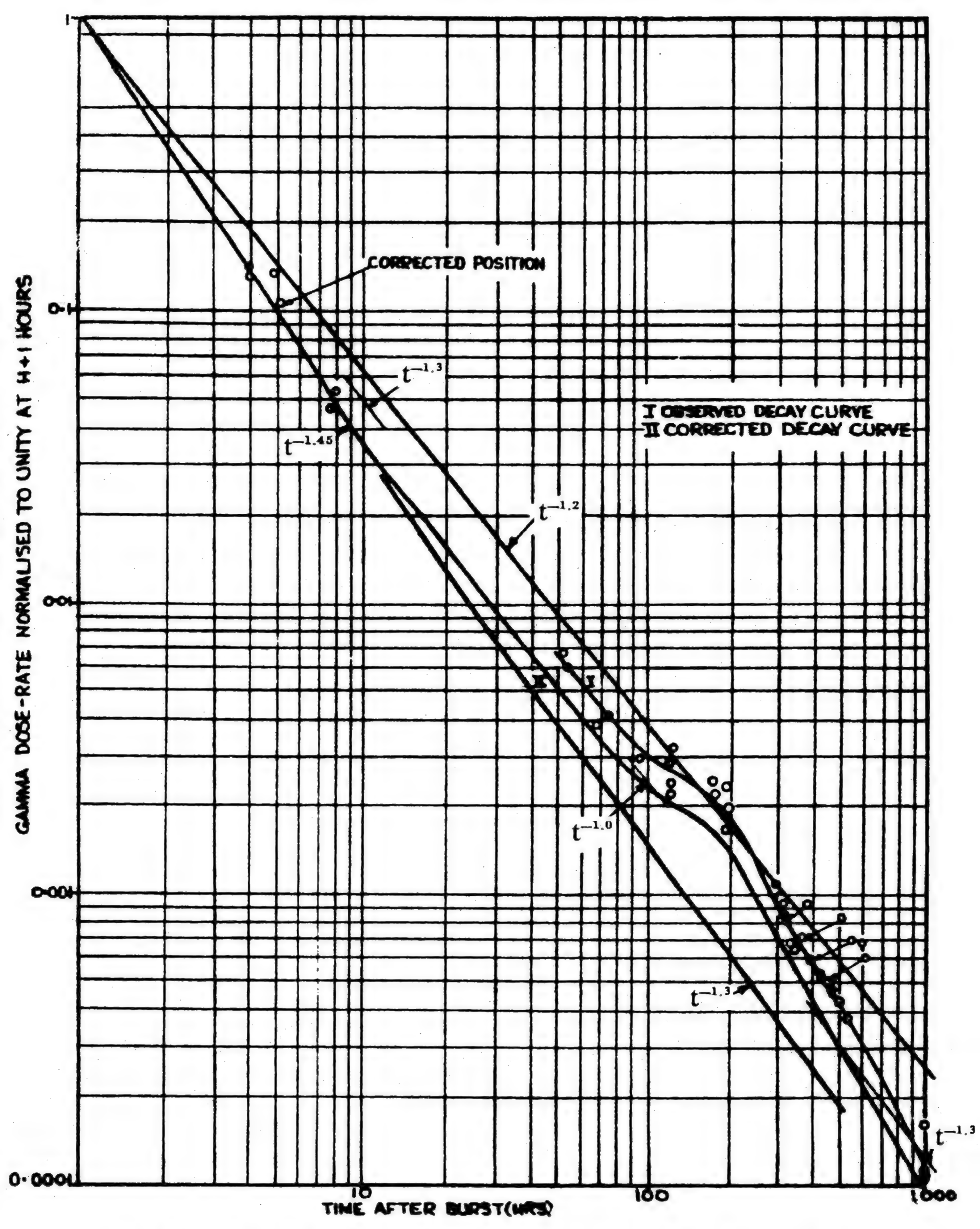


FIG.7·1 DECAY OF GAMMA DOSE-RATE WITH TIME.

(NORMALISED TO UNITY AT H+1 HOUR)

7.4. *Variation of Dose-rate with Height*

Observations were made of the variation of the dose-rate with height above the ground in order to determine whether the dose-rate on the ground could be inferred from measurements made by an aircraft flying at a known height above the ground.

The important practical conclusion was reached that dose-rates obtained by helicopter survey at a given height above a location will enable an estimate to be made of the dose-rate on the ground. The observed dose-rate at 100 feet should be multiplied by 2·5 and that at 500 feet by 10 to obtain the ground level value.

7.5. *Air-borne Contamination and the Inhalation Hazard*

Measurements were made to obtain data on the inhalation hazard in areas of heavy contamination and to assess its magnitude relative to the external hazard from the deposited activity. Samples of air were taken during the period following the explosion by means of standard air samplers working on the vacuum cleaner principle. The air was drawn through a filter paper of which the activity was subsequently measured, and the total volume passed was recorded on an anemometer. The air sampled was that which would have been inhaled by a man walking alone. In three cases it was arranged for dust to be stirred up by walking up and down in windward of the sampler while the sampling was in progress. A visible dust deposit was collected on the filter papers in consequence.

The results of these measurements are given in Table 7.1.

TABLE 7.1

Date	*Time*	*Activity of Sample Microcuries/c.c.*	*Dose rate of Contamination on Ground Milliroentgens/hr.*	*Ratio of Activity to Dose rate*
D-day	H+1 hour	$1{\cdot}9 \times 10^{-4}$	$1{\cdot}7 \times 10^{7}$	$1{\cdot}1 \times 10^{-11}$
D-day	H+2 hours	$1{\cdot}9 \times 10^{-4}$	$6{\cdot}1 \times 10^{6}$	$3{\cdot}1 \times 10^{-11}$
D-day	H+3 hours	$5{\cdot}7 \times 10^{-6}$	$3{\cdot}5 \times 10^{6}$	$1{\cdot}6 \times 10^{-12}$
D-day	H+4 hours	$5{\cdot}1 \times 10^{-6}$	$2{\cdot}3 \times 10^{6}$	$2{\cdot}2 \times 10^{-12}$
D+8		$6{\cdot}2 \times 10^{-10}$	1	6×10^{-10}
D+8		$6{\cdot}8 \times 10^{-9}$	8	$8{\cdot}5 \times 10^{-10}$
D+8		$7{\cdot}2 \times 10^{-8}$*	65	$1{\cdot}1 \times 10^{-9}$
D+8		$8{\cdot}8 \times 10^{-8}$*	15	$5{\cdot}9 \times 10^{-9}$
D+8		$1{\cdot}7 \times 10^{-7}$*	200	$8{\cdot}6 \times 10^{-10}$
D+8		$3{\cdot}1 \times 10^{-9}$	7·2	$4{\cdot}3 \times 10^{-10}$
D+16		$1{\cdot}36 \times 10^{-8}$	25	$5{\cdot}4 \times 10^{-10}$
D+16		$1{\cdot}14 \times 10^{-8}$	15	$7{\cdot}6 \times 10^{-10}$
D+16		$1{\cdot}88 \times 10^{-8}$	200	$9{\cdot}4 \times 10^{-11}$
D+18		$7{\cdot}2 \times 10^{-7}$	1,000	$7{\cdot}2 \times 10^{-10}$
D+18		$1{\cdot}5 \times 10^{-7}$	450	$3{\cdot}3 \times 10^{-10}$
D+18		$5{\cdot}1 \times 10^{-8}$	100	$5{\cdot}1 \times 10^{-10}$
D+18		$4{\cdot}9 \times 10^{-8}$	150	$3{\cdot}3 \times 10^{-10}$

* Dust stirred up by walking to windward of sampler.

There appears to be an approximate relationship between the dose-rate given by the contamination of the ground and the airborne activity associated with it. This relationship is 7×10^{-10} microcuries/c.c. per milliroentgen/hour under the particular conditions existing at Monte Bello. From this the values given in Table 7.2 are obtained for the total activity that would be inhaled while various integrated external doses were received.

TABLE 7.2

External Dose Received	*Fission Products Inhaled*
1 milliroentgen	$8{\cdot}7 \times 10^{-4}$ microcuries
100 ”	$8{\cdot}7 \times 10^{-2}$ ”
1 roentgen	0·87 ”
25 ”	22 ”
50 ”	44 ”
100 ”	87 ”
400 ”	348 ”

8. Underwater Shock Measurements

By means of mechanical gauges underwater shock measurements were made over the range 900 to 3,600 feet by staff of the Naval Construction Research Establishment of the Admiralty. Very few positive results were obtained because of the very low value of the underwater pressures.

Five different types of gauge were used, of which only one type gave measurable records. This was a 6-inch copper diaphragm gauge suspended at half-depth, 22 feet, and consisting of a heavy steel cylinder approximately 10 inches long with a 0·2-inch thick annealed copper diaphragm bolted on to each end. The mean deflection of the two diaphragms of each gauge was used to assess the dynamic peak pressure from the calibration curves.

Measurable deflections were obtained at only the two nearest distances, *i.e.*, 960 and 1,185 feet. The values obtained are shown in the Table 8.1 below in comparison with values given by similar gauges in Test Baker at Bikini where the bomb was fired at half-depth in water 200 feet deep.

Table 8.1

	Pressure (p.s.i.)	
Distance	*Monte Bello*	*Bikini Test B*
5,000	...	150
4,000	...	260
3,000	Negligible	490
2,000	Negligible	950
1,185	20	...
960	270	...

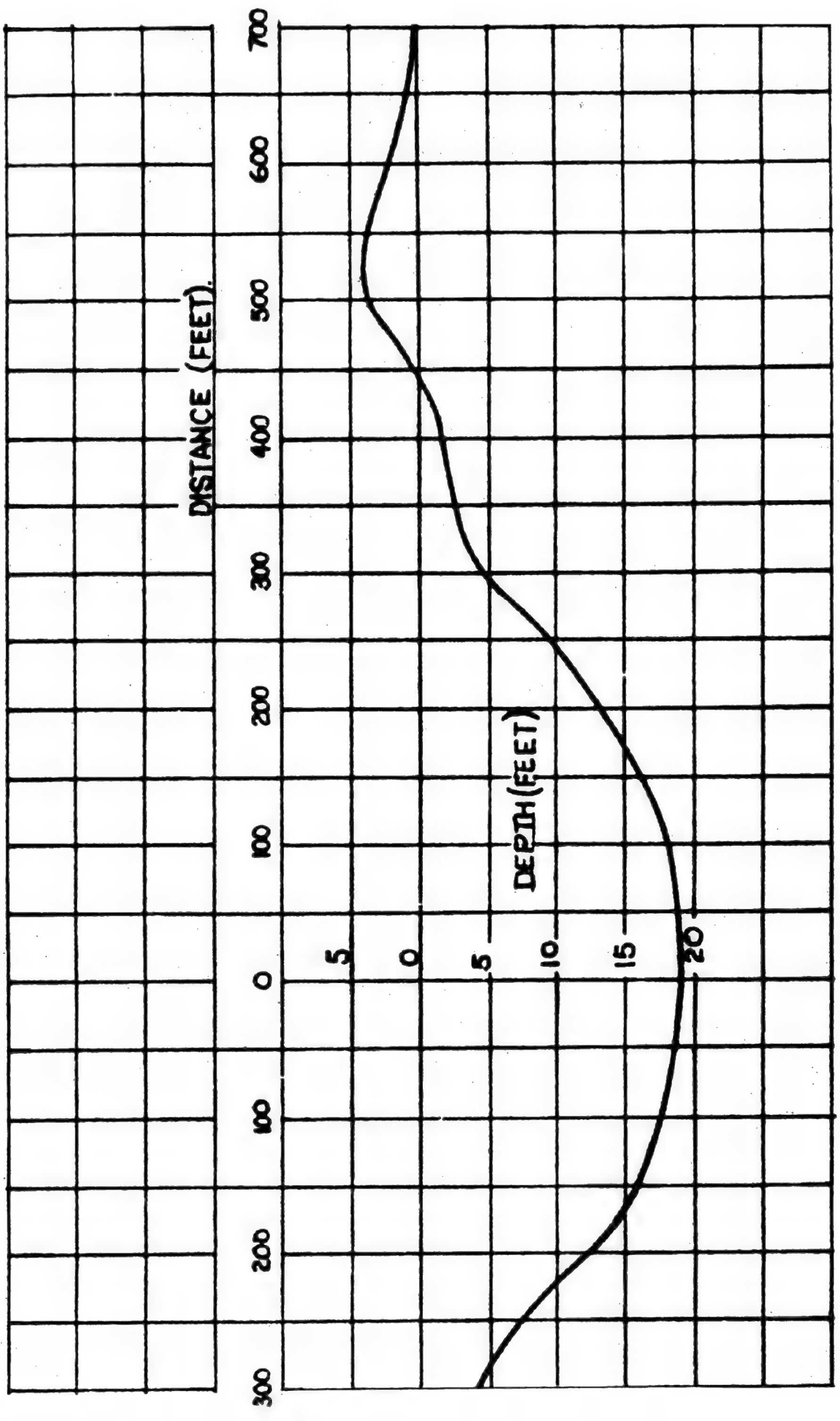
The very low underwater pressures obtained indicate that in an explosion in a ship and very near the water-line little of the energy is transmitted to the water as a pressure wave and that, in shallow water, the quantity of energy that does enter the water in this way is very rapidly attenuated by the surface cut-off action.

If a pressure criterion is applicable it appears, by comparison with observed damage to ships at Bikini, that slight to medium underwater damage to surface ships would occur between 800 and 1,000 feet and no material damage beyond 1,000 feet whilst a submarine, submerged at half-depth, might be sunk or seriously damaged at 800 feet and yet only slightly damaged at 1,000 feet. Judging from the results of Test Able at Bikini, at 1,000 feet the damage from air blast would cause almost total destruction to all but capital ships. Thus for a near-surface burst in very shallow water, the distance for structural safety of surface ships and surfaced submarines is likely to be determined by air blast.

9. Crater

The crater formed in the sea-bed was a shallow saucer-shaped depression some 1,000 feet across and 20 feet deep at the centre with a lip averaging 4 feet in height. Its contour was determined by a survey of the sea-bed in the vicinity of the burst, before and after the trial, by means of echo soundings along six diametrical lines, 30 degrees apart and intersecting approximately in the position of the weapon. Fig. 9.1 shows the mean depth change between the two surveys over the six diametrical lines as a function of distance from the centre.

Before the explosion the sea-bottom in this region was a coarse sand composed of crushed coral, and for about 500 feet on each side of the weapon position it was fairly flat, differences from the mean depth not exceeding some 5 to 8 feet. It was at first thought that there was a layer of mud above the coral because of a black deposit which was found on objects in the fall-out area. This has since been identified at the Admiralty Materials Laboratory as being composed of 90 per cent. magnetic oxide of iron and 10 per cent. ferrous oxide and is therefore the remains of H.M.S. *Plym* and not mud.



CRATER CONTOUR.

DEPTHS ARE MEAN VALUES FOR SIX DIAMETRICAL LINES.

FIG. 9.1

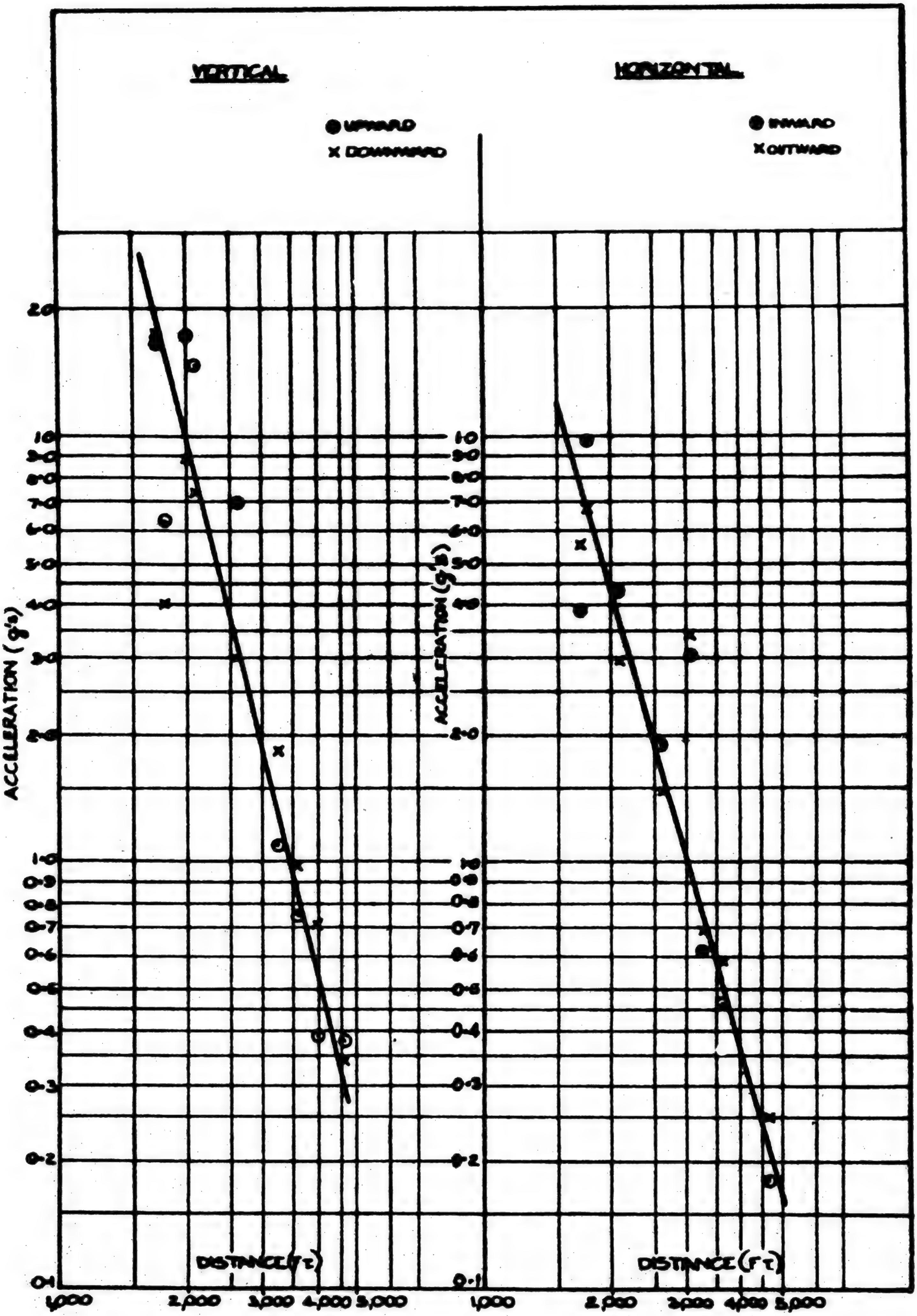
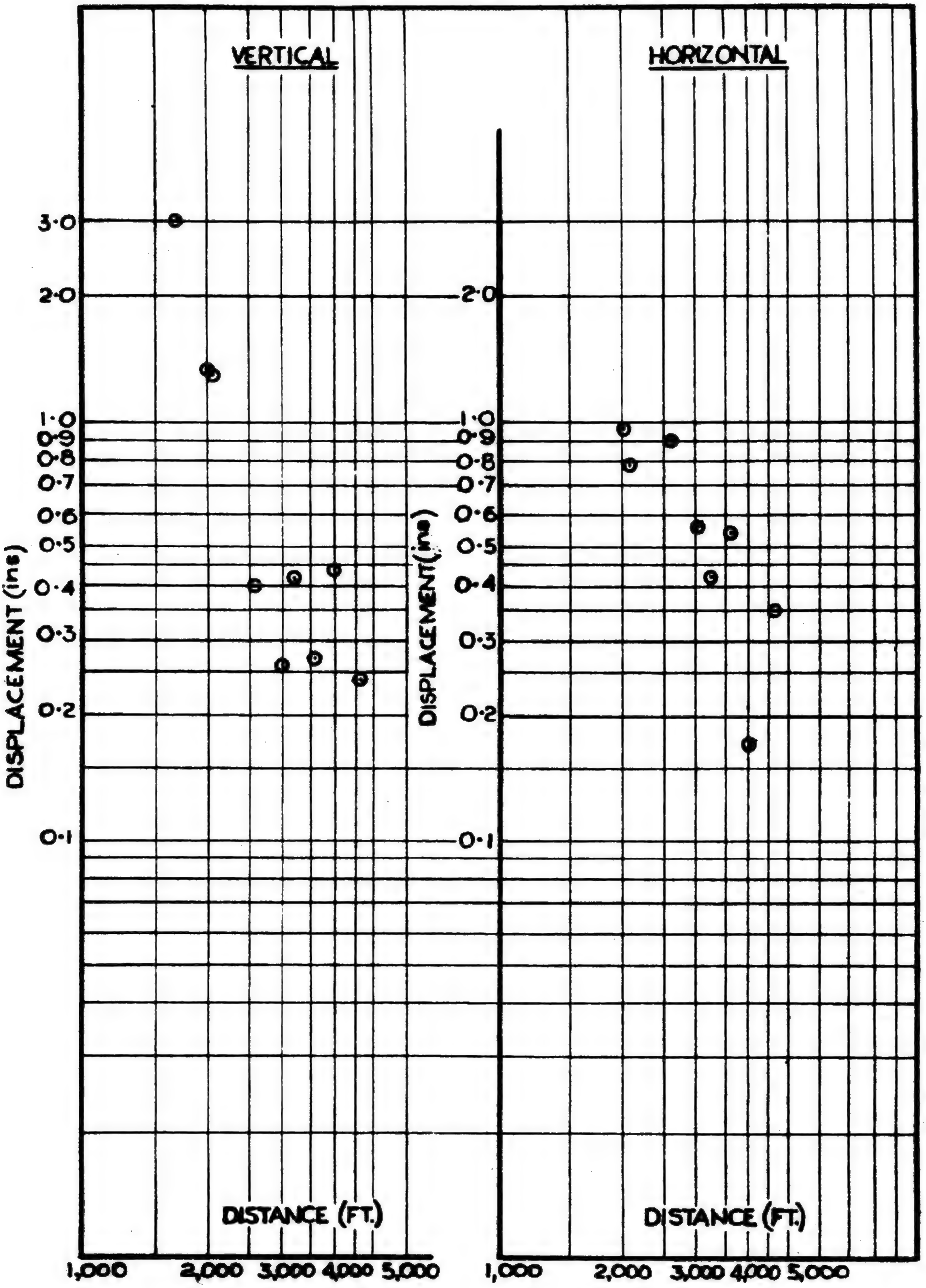


FIG.10·1. MAXIMUM ACCELERATIONS.



PEAK TO PEAK MAXIMUM DISPLACEMENTS.

FIG.10·2

12. Blast Effects

12.1. *Blast Damage to Anderson Shelters*

12.1.1. In accordance with certain requirements of the Chief Scientific Adviser to the Home Office, fifteen Anderson shelters were erected, three at each of five sites situated, on Trimouille Island, more or less due West of the explosion at distances of 1,380, 1,530, 1,800, 2,760 and 3,390 feet. In each group one shelter was placed with its entrance facing the explosion, one with the entrance facing away from the explosion and one sideways to it.

The shelters were erected with a blast wall shielding the entrance, by the normal procedure laid down by the Ministry of Works, there being a difference from the usual practice in this country in that the covering of the shelter and the filling of the blast wall, instead of being earth, consisted of sandbags filled with fine dune sand, the only material available. The shelters were sunk with their floors about 4 feet below ground level; the thickness of the sandbags averaged 18 inches directly over the top of the roof arch to about 3 ft. 6 ins. at ground level at the sides. The blast wall was from 2 ft. to 2 ft. 6 ins. thick contained within sheets of corrugated iron and was placed about 3 feet from the shelter.

12.1.2. In the groups of shelters at 1,380, 1,530 and 1,800 feet, the sandbags covering them were almost entirely blown away and the blast walls were destroyed.

At 1,380 feet, Fig. 12.1, parts of the main structure of the shelters facing towards and sideways to the explosion were blown in but the main structure of the one facing away from the explosion was intact, and would have given full protection. At 1,530 feet, Fig. 12.2, the front sheets of the shelter facing the explosion were blown into the shelter but otherwise the main structures were more or less undamaged, as were those at 1,800 feet, Fig. 12.3.

At 2,760 feet, Fig. 12.4, some of the sandbags covering the shelters were displaced and the blast walls were distorted whilst at 3,390 feet, Fig. 12.5, the effect was quite small. At these distances, the shelters were not in direct view of the explosion owing to intervening sandhills.

12.2. *Maximum Pressures Inside Anderson Shelters*

Measurements of the maximum pressures inside the Anderson shelters were obtained using the toothpaste tubes referred to in paragraph 4.1.

The results obtained are summarised below in Table 12.1.

Table 12.1

Distance from Burst (Feet)	*Maximum Excess Pressure in Incident Blast* (p.s.i.)	*Maximum Pressure Inside Shelter* (p.s.i.)		
		Door towards Burst	*Door sideways to Burst*	*Door away from Burst*
1,530	48	38	27	40·5
1,800	31·5	28	21	28
2,760	12	16	7	13·5
3,390	8	8·5	4	5·5

No results were obtained at the nearest distance of 1,380 feet.

12.3. *Blast Damage to Concrete Cubicles*

12.3.1. A number of concrete cubicles designed by the Ministry of Works were erected to obtain some information on the failure of reinforced concrete structural units under the action of the blast from an atomic bomb.

12.3.2. *Details of the Cubicles*

The original intention was to construct nine cubicles with internal dimensions of 12 feet and with wall and roof thicknesses of 6, 9 and 12 inches respectively. They were all designed to resist a uniform transverse load of 300 lbs./sq. ft. (2·1 p.s.i.), adopting conventional elastic theory. It was intended that one cubicle

Fig. 12.1, Andersons at 1380 ft range from bomb ship shown in the photo, anchored 400 yards off shore.

Left: Fig. 12.3, Andersons at 1800 ft after burst. Right: Fig. 12.4, Andersons protected by blast walls at 2760 ft.

of each thickness should be placed at distances where the peak excess hydrostatic pressure in the blast was expected to be 6, 10 and 25 p.s.i.

It transpired, however, that there was only sufficient time available at the site to construct five cubicles. Moreover, in order to permit the use of 1¼ inch aggregate, the proposed 6-inch and 9-inch walls had to be modified to 6¾ and 9¾ inches respectively.

The cubicles were situated as follows:—

TABLE 12.2

Distance (Feet)	*Peak Hydrostatic Pressure in the Incident Blast* (p.s.i)	*Wall Thickness* (Inches)		
1,815	31		9¾	
2,970	10	6¾	9¾	12
3,975	6		9¾	

The reinforcement of MS rods to British Standard Specification 785 and the cement, Ferrocrete Rapid Hardening, were shipped from the United Kingdom. The aggregate was obtained by crushing local rock to a maximum size of 1¼ inches. The rock had a granular surface, a bulk density of only 72·5 lbs. per cu. ft., and was very weak. Chemically it consisted mainly of calcium carbonate.

The sand was obtained from the beach nearby; it was somewhat fine, 70 per cent. passing through a No. 25 sieve. The concrete was made using sea water.

Normal methods of construction were adopted throughout, the walls being cast in 3-ft. lifts. Compaction was done with tamping rods.

The mix used was 1 part cement, 1·4 parts sand, 2·8 parts aggregate (all by volume) with a water/cement ratio of 0·48. This was a richer mix than would normally be used for concrete made with ballast aggregate but it was found to be necessary, owing to the poor quality of the local aggregate, in order to obtain a suitable strength combined with reasonable workability. The density of the concrete so obtained averaged only 133 lbs. per cu. ft. Tests on bin cubes at 7 days gave a crushing strength ranging generally between 2,000 and 3,000 p.s.i. Tests on plain concrete beams gave a modulus of rupture varying from about 300 to 500 p.s.i.

12.3.3. *Description of Damage*

There were no indications that any of the cubicles was tilted or translated bodily.

The only cubicle that sustained any serious damage was the one at 1,815 feet in which the wall facing the explosion was completely destroyed, a large portion of it being pushed inwards and hurled against the rear wall. There were some instances of failure of the reinforcement in this panel, but, in the main, failure of the concrete caused collapse, the concrete being either stripped from the bars or failing in bond, the latter being very evident along the bottom edge. Figs. 12.6 to 12.9 show this cubicle before and after the explosion.

The two side walls were left slightly bowed outwards and showed typical fine cracks from the corners to the centre. There was some failure at the construction joints near the front edges of these walls, as shown in Fig. 12.8. The extent of the bowing was not measured but its magnitude was estimated as about 1 inch. It could not be ascertained whether or not these walls had been first deflected inwards and then, after the failure of the front wall, pushed outwards.

The roof showed some cracks which roughly followed the line of the inside faces of the walls and there was failure above the inside edge of the front wall. Only a few hair cracks could be found in the rear wall.

At 2,970 feet the cubicles with 6¾ and 9¾-inch walls showed some fine hair cracks which did not extend to the inner surface, a typical example being shown in Figs. 12.10 and 12.11.

The cubicle with 12-inch walls showed no indication of any damage and the same applies to the one with 9¾-inch walls at 3,975 feet.


Fig. 12.6 and Fig. 12.7. Concrete cubicle at 1815 ft.

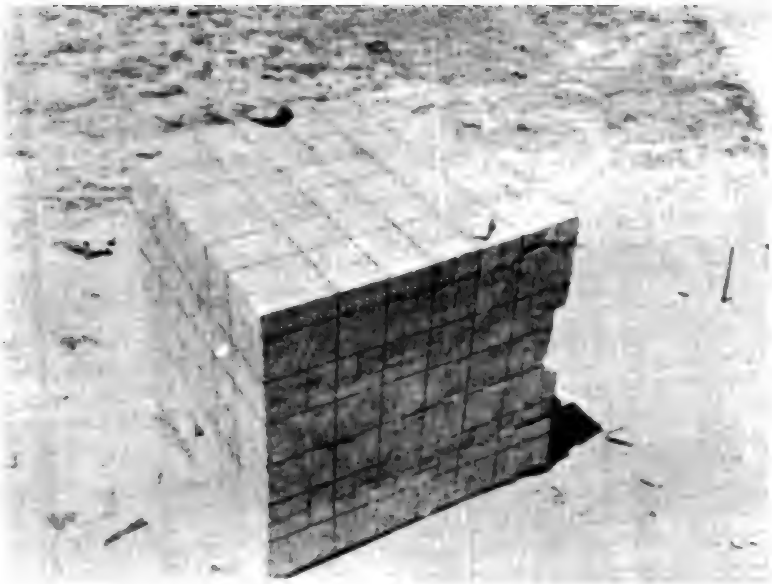



Fig. 12.8 and Fig. 12.9. Concrete cubicle at 1815 ft.

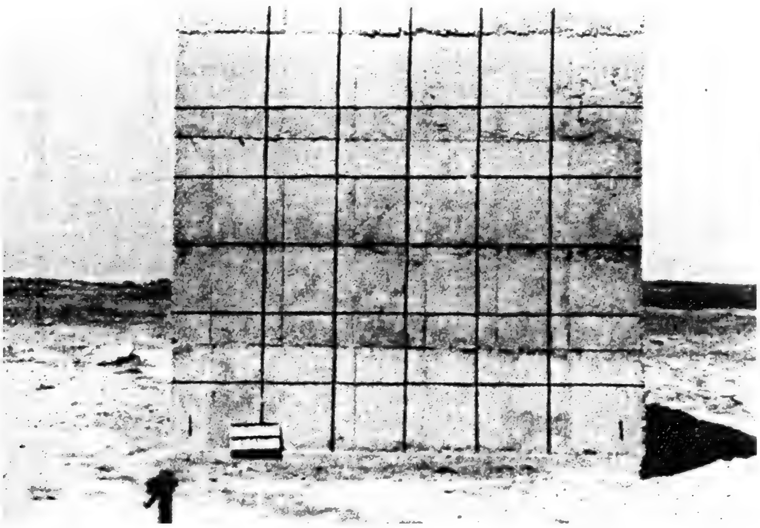
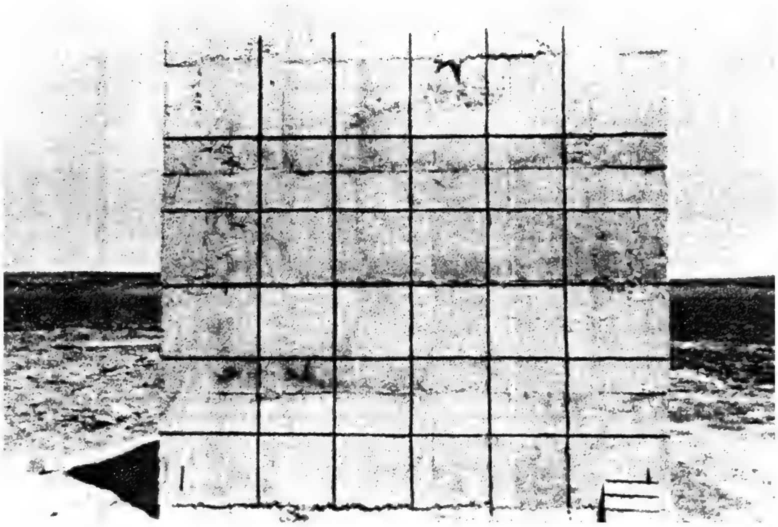



Fig. 12.10 and Fig. 12.11. Concrete cubicle at 2970 ft

13. The Penetration of the Gamma Flash

13.1. *Experiments on the Protection from the Gamma Flash afforded by Slit Trenches*

13.1.1. The experiments described in this section show that slit trenches provide a considerable measure of protection from the gamma flash. From the point of view of Service and Civil Defence authorities this is one of the most important results of the trial.

13.1.2. Rectangular slit trenches 6 ft. by 2 ft. in plan and 6 ft. deep were placed at 733, 943 and 1,300 yards from the bomb and circular fox holes 2 ft. in radius and 6 ft. deep were placed at 943 and 1,300 yards.

The doses received from the flash were measured with film badges and quartz-fibre dosimeters in order to determine the variation of protection with distance, with depth and with orientation of the trench and the relative protection afforded by open and covered trenches.

In general, the slit trenches were placed broadside-on to the target vessel but at 1,300 yards one trench was placed end-on. Two trenches, one at 733 and one at 943 yards were covered with the equivalent of 11 inches of sand.

13.1.3. A few results were obtained to show the variation of dose in a horizontal plane inside a trench and these indicated that the dose at a given depth is not likely to differ from that measured on the vertical axis by a factor greater than 2·5 even at the remote ends. Such differences are insignificant compared with those accompanying a change in depth so that the degree of protection can be assessed simply from the dose received on the vertical axis of the trench. A summary of the results obtained is given in Table 13.1. The surface doses are taken from the mean curve for the gamma flash dose given in Fig. 5.1.

13.1.4. From these experiments the following general conclusions may be drawn:—

(*a*) Open slit trenches, nominally 6 ft. × 2 ft. × 6 ft. deep provide a considerable degree of protection from the gamma flash and this increases with depth but at a decreasing rate.

(*b*) The approximate doses received by a man standing erect on the vertical axis of such a trench, averaged for all orientations of the trench are given below:—

Distance in yards ...	1,300	943	733
Dose in Roentgens	55	240	1,070

Thus personnel protected in this way would receive the median lethal dose of 400r at about 850 yards compared with just under 1,300 yards when exposed on the surface.

(*c*) Personnel lying prone in open slit trenches 3 ft. or more in depth should not receive the median lethal dose even as close as 733 yards.

(*d*) A top cover equivalent to one foot of earth reduces the dose experienced inside a trench by a factor of about 5 so that, under these conditions, median lethal dose for a man standing erect would be received at a distance of about 650 yards.

(*e*) The dose received on the vertical axis of trenches of rectangular cross-section and which had random orientation, do not differ greatly from those on the vertical axis (at the same depth) of cylindrical trenches of the same area of cross-section.

(*f*) This experimental data, showing how great is the protection afforded by slit trenches, provides one of the most important results of the trial from the point of view of Service and Civil Defence authorities.

TABLE 13.1

Variation of Gamma Flash Dose on Vertical Axis of Trench

Type of trench	Rectangular broadside-on open			Rectangular end-on open	Circular open		Rectangular broadside-on covered	
Distance (yards) ...	1,300	943	733	1,300	1,300	943	943	733
Surface dose (Roentgens)	300	3,000	14,000	300	300	3,000	3,000	14,000
Depth below ground level (inches)								
6 ...	150	1,000	—	230	214	1,200	(75)	—
12 ...	75	430	—	150	120	545	47·6	—
24 ...	33·3	150	584	60	54·5	188	25	(140)
36 ...	23	70	216	31·6	30	86	13	(56)
48 ...	(20)	43	100	20	17·7	48·5	7·7	(31)
60 ...	—	(37·5)	61	13·6	10·7	(33·3)	5	(23)
72 ...	—	—	(46·7)	(8·6)	7	—	(3·5)	—

Entries in brackets are extrapolations or estimates.

13.2. *The Penetration of the Gamma Flash into Anderson Shelters and Concrete Cubicles*

13.2.1. Film badges were used to measure the gamma flash dose inside Anderson shelters and concrete cubicles. The latter were erected primarily to study the effect of blast on reinforced concrete panels but because of their regular shape and appropriate range of panel thickness were well adapted for the study of gamma-ray penetration.

In the Anderson shelters, the floors of which were situated at a depth of 3 ft. below ground level, four film badges were disposed, two above ground level and two below. Four badges were also placed in the concrete cubicles, along the horizontal axis of symmetry pointing towards the weapon, (*a*) in the centre of the cube, (*b*) against the front wall, (*c*) against the rear wall and (*d*) at a distance of one foot from the front wall.

13.2.2. The results of these measurements are summarised in Tables 13.2 and 13.3 together with estimates of the dose received outside the cubicles.

The results for Anderson shelters show considerable scatter but some broad conclusions can be drawn. It is clear that for a burst near ground level, the dose below ground level was about half that above ground, but this would not necessarily apply to an airburst, where more of the radiation would come through the roof. The shelter as a whole was quite effective in reducing the dose and the median lethal dose of 400r would be received at about 2,400 ft. below ground level and at about 2,700 ft. above, as compared with 3,900 feet in the open. The advantage of getting down on the floor is further illustrated by the fact that at 2,700 ft. the dose received at floor level would be only 150r which may be regarded as generally non-lethal, whereas the median lethal dose would be received above ground level.

The results for the cubicles indicate complete protection against lethal effects of radiation, *i.e.*, a dose of 100–150r, inside a reinforced concrete structure with walls 12 inches thick at about 3,300 ft. and for 6½-inch wall thickness in the region of 3,900 ft. where the dose in the open would be the median lethal dose of 400r.

TABLE 13.2

Gamma Flash Doses in Anderson Shelters

Distance (Feet)	*Estimated Dose Outside* (r)	*Average Dose Inside* (r) *Above Ground Level*	*Below Ground Level*
1,380	75,000	N.R.	10,500
1,530	47,000	11,000	5,500
1,800	30,000	7,000	2,000
2,760	4,000	150	100
3,390	1,200	30	15

TABLE 13.3

Gamma Flash Dose inside Concrete Cubicles

Distance (ft.)	Estimated dose outside (r)	Dose inside (r)			Average dose inside (r)
		Wall thickness (inches)	Position of badge (see text)	Dose	
		6¾	a	410	
			b	455	
			c	430	460
			d	545	
			a	260	
2,970	2,800	9¾	b	—	
			c	230	270
			d	322	
			a	185	
		12	b	220	
			c	158	190
			d	195	
3,975	380	9¾	a	35	
			b	62	
			c	46	50
			d	58	

The front of the cubicle at 1,800 ft. was blown in and the badges were exposed to radiation from the fall-out.

14. THE EFFECT OF HEAT FLASH ON MATERIALS

14.1. Samples of cloth, service clothing and equipment, black-out materials and temperature indicating lacquers were set out at various distances from the weapon. This work was organised by staff of the Scientific Adviser to the Army Council, of the Home Office and of the Admiralty. Owing to the small amount of heat radiated by explosion under the particular conditions of the test, very few positive thermal effects were obtained.

14.2. A preliminary report from the Scientific Adviser to the Army Council gives the following observations:—

(i) Some scorching of cloth samples set up on panels at 500 yards was observed.

(ii) No effects were observed on the following:—

Samples of R.A.F. flying clothing exposed at 1,000 and 1,500 yards. Norman battle-dress or combat suits with respirators and steel helmets exposed at 1,000, 1,200 and 1,400 yards.

Gas capes and pouches at 1,000 yards and beyond.

Black-out materials, treated and untreated, fully exposed and behind clear and white-washed glass, together with temperature indicating lacquers on mild-steel plates at 1,000 yards and beyond.

Pieces of fibre-board and dummies representing the human arm covered with shirt and battledress serge at ranges of 1,000 yards and above.

(iii) Samples of black-out material and heat-indicating lacquer exposed at 500 yards received heavy contamination and have not yet been fully examined.

14.3. A service respirator face-piece, a civil defence respirator face-piece, a civilian respirator and a children's respirator were exposed at six positions between 450 yards and 1,000 yards. At all sites severe blast damage occurred and at the nearest nothing of the masks was recovered. At the other distances, *i.e.* between 500 and 1,000 yards, where in some cases only parts of the respirators were found, there was no sign of flash burn.

14.4. For one of the Naval ABC trials, canvas wallets, on to which were sewn samples of different types of naval clothing, were set up at twelve points between 750 and 3,500 yards from the explosion. The results were almost entirely negative, the only material affected being IA8 blue serge which had a very slight surface scorch at 750 yards.

15. Contamination and Decontamination

15.1. The results and conclusions quoted here can be applied only to the type of conditions experienced at Monte Bello, *i.e.*, to a dry dusty location or to dry debris resulting from the destruction of buildings. They also apply to reconnaissance, rather than rescue or other dust-raising operations, with entry to the contaminated area after fall-out has occurred and any fluid fall-out has dried. The contamination will then be tightly absorbed on to the dust particles and decontamination is then largely achieved by removing the dust. Contamination from direct fluid fall-out was found to be strongly absorbed by the surface and its removal was very difficult.

15.2. *Protective Clothing*

15.2.1. For the use of personnel entering contaminated areas a standard issue was made of protective clothing. This consisted of cotton singlet and trunks, woollen socks, a combination suit, rubber undergloves, cotton overgloves, half wellington boots, a light service respirator and a hat, something like a trilby. The combination suit had double legs from just below the knee, the inner one being caught under the foot by means of a loop. The sleeves were double from the elbow, the inner sleeve being retained in place by a loop passing over the thumb. Both the inner leg and inner arm had elastic around the bottom. A sweat-rag was worn round the neck. The following notes are given to illustrate the lessons learned and conclusions reached, not always unanimous, concerning its protective value and general usefulness.

15.2.2. *Suits*

General opinion agreed that the combination suit was surprisingly comfortable although for use in a hot climate a lighter colour would have been preferable. The material was splash-proof but not water-proof and its weave seemed to be a fair compromise between reasonable ventilation and the need to keep out contaminated dust. It was generally effective in preventing body contamination but where the dust was rubbed or pressed in, *e.g.*, at the knees or elbows or round the legs when pushing through the long spinifex grass, it penetrated the suit and contamination of the skin resulted. Thicker material or the use of long pants or vests with sleeves would prevent this but would be impracticable for hot climates. Elastic at the bottom of the legs and sleeves is liable to be damaged during laundering and tapes would have been preferable.

15.2.3. *Sweat-rags*

The sweat-rags used were not of the type expected and made only a defective seal. They allowed perspiration to trickle on to the shoulders and thus caused contamination which was sometimes difficult to remove. The necessity for a sweat-rag would be obviated by the use of a hood as recommended later.

15.2.4. *Headgear*

The hats provided were unsuccessful as they did not prevent dust-borne and air-borne contamination from collecting on the exposed parts of the head and face. It was clear that only a hood would prevent head contamination.

15.2.5. *Respirators*

Although it was found that the respirators provided could be worn for long periods, heavy work was rendered difficult by condensation of perspiration inside the mask. It was felt generally that for fire or dust-raising operations, it is highly desirable to have some form of respirator and for trials purposes these should be worn in all significantly contaminated areas. Further investigation on the most suitable type is clearly required, *e.g.*, a light industrial dust mask and eye-shield might be adequate.

15.2.6. *Gloves*

Owing to the heat the rubber gloves were unpleasant to wear and were liable to be torn in heavy work. They were also surprisingly difficult to decontaminate. A plastic impregnated material might be more suitable, or alternatively the use of two separate expendable gloves, *e.g.*, a light cotton close-fitting underglove and a heavier reinforced overglove. Experience with the suit and underwear showed that two layers of material would prevent contamination and at the same time allow reasonable ventilation and sweat absorption. Two gloves were found to be necessary at Monte Bello when records were being recovered from contaminated regions, but for general use it would probably be better to have a single glove if a suitable material could be found.

15.2.7. *Boots*

The rubber half-wellingtons used in conjunction with a double trouser leg (one inside the boot and one outside) were effective in reducing foot contamination. Their disadvantage lay in the difficulty of decontaminating them which was accentuated by the matt finish and the indented pattern of the sole of those supplied. A boot with a high gloss would probably be easier to decontaminate or an expendable overboot might be considered.

15.3. *Body Contamination*

15.3.1. *Removal of Body Contamination*

During the three weeks following the burst about 940 man-sorties were made into the contaminated areas. All personnel who had worn protective clothing had to take a shower, as a matter of routine procedure, although many, *e.g.*, boats crews, had not entered areas of appreciable contamination. No records were kept of the number of cases where there was no appreciable contamination before the first shower. In only 18·4 per cent. of cases was further treatment necessary.

The effectiveness of the various treatments is summarised below:—

Treatment	*Percentage*
No significant contamination after first shower ...	81·6
Contamination removed by re-wash only	5·5
Contamination removed with titanium dioxide and Teepol* followed by re-wash	8·3
Further treatment with potassium permanganate and re-wash	3·7
Release, after preceding treatments, with slight residual contamination	0·9

* Later precipitated chalk and Teepol.

Personnel who were released with slight contamination lost much of it within two days.

The heaviest contamination was found on members of a party which was engaged in a variety of activities in the worst contaminated area of Trimouille. They registered a gamma activity of between 3 and 6 milli-roentgens per hour. The total dose rate in the area in which they worked was between 5 and 10 roentgens per hour and the total gamma dose received by each person was about 3r. Even in these cases the first shower-bath removed the bulk of the activity.

15.3.2. *Location of Body Contamination*

The following summary shows the number of instances in which contamination was found on the various parts of the body after the first shower:—

Neck	*Face*	*Hair*	*Knees and Legs*	*Hands*	*Shoulders*	*Arms*	*Chest*	*Feet*
91	67	67	54	27	10	7	3	1

The location of the contamination varied with time. For example, about seven days after the burst, entry into areas of heavy contamination was possible and an increased number of contaminated knees and legs was caused by pushing through knee-deep vegetation. Later the boats became contaminated and this was spread to the knees and legs by sitting on the decks.

15.4. *Decontamination of Equipment*

15.4.1. *General Procedure*

The procedure adopted fell into three main classes

(i) depending on complexing action involving the use of citric and other acids to form soluble complexes with certain of the fission products which are less easily absorbed on surfaces;

(ii) normal cleansing action with wetting agents such as Teepol and degreasing agents such as trichlorethylene, Butex and Irgalon, which may also have valuable complexing actions;

(iii) absorption with fine powders such as titanium oxide or precipitated chalk which present large effective surface areas.

15.4.2. *Decontamination of Instruments*

Loose dry contamination was first removed by cleaning by means of a dry rag or by vacuum cleaning. It was found to be important not to wet the surfaces before this was complete, for it the surface were wetted the fission products tended to be carried in solution on to the surface and to be strongly absorbed. When time allowed, dry cleaning was followed by storage to allow further decay of radioactivity.

If wet treatment was necessary, the procedure consisted in first rinsing with fresh water, and following it, if necessary, with a mixture of 5 per cent. citric acid and 1 per cent. Teepol in equal parts. Precipitated chalk was also used.

It was found to be important that electronic equipment for use in the field should be completely watertight so that it can be washed down. Rubber seals should be designed so that the minimum crevice is left into which contamination can lodge and so that joints can easily be remade after servicing. All surfaces should be as smooth as possible and recesses, screw holes, slots and knurled knobs avoided. Even then everything should be done to prevent contamination of monitoring instruments and the use of expendable covers or bags, is strongly recommended.

Experience with a ciné camera illustrates the difficulty of removing contamination due to direct fluid fall-out. This camera was not recovered until the fifth day and even though the surfaces appeared clean there was heavy contamination which was only reduced by about 20 per cent. after practically all the various treatments had been tried at a prohibitive cost in time. It was finally cleaned in the United Kingdom by complete removal of the black instrument finish.

It was also found to be practically impossible to decontaminate the fabric instrument carrying cases and haversacks by any simple process such as scrubbing. It is clear that expendable cases made of plastic or plastic-impregnated material with smooth surfaces are required for this purpose.

15.4.3. *Decontamination of Boats*

By the end of the operation the outer surfaces of the boat hulls were not seriously contaminated as the contaminated water had dispersed and the hulls had been cleansed by much passing through clean water. Cordage, canvas and bare wood fittings which retained radioactive products were finally jettisoned. Contamination of decks was never high, and at the end of the operation was removed by scrubbing and hosing after which the boats were hoisted at the davits and left for the radioactivity to decay.

15.5. *Contamination of Ships*

Some build-up of contamination occurred in certain parts of the engine room of the Health Ship due to the circulation of contaminated sea water. In the circulator and the weed trap the dose-rate rose to a higher level than that in the water outside and reached a value as high as 6 mr/hr. It was concluded that contamination of the engine room will be the limiting factor in assessing the level of water contamination into which a ship may be permitted to sail. At Monte Bello the contamination level was never serious and would not have restricted operations.

15.6. *Special Decontamination Trials*

15.6.1. *Trial of Decontamination under Service Conditions*

The steel deckhouse, referred to in section 12.6 under blast effects, received a heavy dose of contamination which gave a dose-rate of 6 r/hr after 19 days.

As part of the Naval ABC trials, decontamination was done by two naval parties, each of which, using a portable pump, hosed down for fifteen minutes with sea-water, three minutes for each bulkhead and three for the roof.

Two removable steel plates were fitted to the deckhouse. One was removed before decontamination and one after and both were sent to the health ship for measurements of the beta and gamma activity. These measurements indicated that the effect of the hosing down was to reduce the gamma activity by 60 per cent. and the beta activity by 70 per cent.

15.6.2. *Reduction of Contamination by the Water Spray Method*

In another Naval ABC trial, an attempt was made to protect surfaces painted with naval light grey weatherwork paint from contamination by spraying with water during exposure to fall-out. The operation commenced shortly before the explosion and continued throughout the fall-out period. One set of samples was sprayed with sea-water and one with a mixture of sea-water and 0·1 per cent. of citric acid. A third set was unsprayed and was used as a control. All samples were inclined at an angle of 30° to the horizontal to minimise the effect of blast and heat.

One set of samples was in a region of heavy fall-out, the dose-rate after 18 days being 5 r/hr. This corresponds to about 10,000 r/hr at 1 hour after burst, a dose-rate which is comparable with that at the centre of a base surge.

Measurements of beta plus gamma activities showed that the activity of samples sprayed with plain sea-water was only 11 per cent. of that of unsprayed samples whilst the use of sea-water and 0·1 per cent. of citric acid reduced the activity to only 4 per cent. of that of unsprayed samples.

15.6.3. A further Naval ABC trial was performed to determine the merits of various surface finishes and materials in regard to ease of decontamination. Small squares (3 inch) of a variety of paints, lacquers, instrument finishes and miscellaneous materials of Service interest were set out in the fall-out area in horizontal frames. At two sites the samples were lightly contaminated by dry fall-out. This fall-out is the type of contamination to be expected from dust distributed by an atomic explosion or carried by the smoke from fires. It is also the type to be expected when civil defence squads enter contaminated areas. Tests showed that about one half of this could be removed from smooth surfaces by rubbing with a dry cloth but complete cleansing required wet treatments. This work is still proceeding.

At a third site liquid fall-out occurred and samples were mottled with a black deposit of contamination which proved to be the remains of H.M.S. *Plym*. The main problem here is to find to what extent and by what process the finishes and materials contaminated by direct fall-out can best be decontaminated. This work is still proceeding at the Admiralty Research Laboratory.

It may be mentioned that the control samples which were used in the spraying tests at the same site and which were inclined at an angle of 30° were completely free of the black fall-out, indicating its very fluid nature. This emphasises the advantage of effective draining of ships' decks and superstructures.

15.7. *Contamination of Stored Food*

15.7.1. At the request of the Ministry of Food a trial was performed by the Home Office representatives to see the effect of an atomic burst on food stored temporarily on a dockside or in dock buildings severely damaged by previous attack, particularly with a view to estimating what proportion of such food could be recovered and made fit for human consumption. Three dumps of food were set up on Trimouille their contents being given in Table 15.1. It should be remembered that the results obtained must be related to the dose-rate rather than the distance since the position at which a given level of contamination was received at Monte Bello was determined by the particular wind conditions obtaining at the time.

15.7.2. At one site, the activity at one hour after burst was estimated to be 100 r/hr. There was no sign of fluid fall-out at this site. Considerable damage was done by blast and some samples were destroyed by fires which almost certainly were started by pieces of red hot metal from the target vessel rather than by heat flash. The activity in samples inside containers varied from 1/20th to 1/2,000th of that on the outsides of the containers which was of the order of 20 micro-curies per sq. cm.

At a second site, there was no appreciable fall-out in the region of the food dump and no disturbance of the food-stuffs by blast or fire.

At the third site, the estimated activity at one hour after the explosion was about 250 r/hr and there was evidence of heavy liquid fall-out in the form of black cloudy rain which covered the upper surfaces of the various packages with black spots giving the surfaces an overall activity of about 50 micro-curies per sq. cm. None of this discolouration penetrated to the inside surfaces of any of the covers. The activity of samples of the contents of the various packages was between 1/10th and 1/100th of that on the outside. The activity of the samples at this site was about ten times that in the samples at the first site although the ground contamination was only 2·5 times as great. This illustrates the greater penetrating power of liquid fall-out. It is also evident that the penetration through woven materials was about ten times that through paper and plywood. In the worst case (of woven sacks) only one-tenth of the activity deposited by the fall-out found its way into the upper layer of food and this activity was of the same order as that stated in Civil Defence Technical Bulletin TB–11–8 to be the permissible emergency level in water and food (0·9 microcuries per cc.) for consumption over a period of ten days.

15.7.3. It is therefore concluded that under heavy contamination of the type which occurred in this test a very high proportion of food exposed in dumps such as those tested would be fit for human consumption. Special care would be required in the handling and disposal of the covers. These considerations, of course, apply to dry atmospheric conditions. It is possible that, if there were heavy rain at the time, penetration through the covers would be much greater.

15.8. *Radiation Hazard, inside a Compartment, due to External Contamination*

Measurements of the gamma dose-rate inside and outside the ¼-inch steel plate deckhouse used for the decontamination experiments described in section 15.6.1 showed that the dose-rate inside the compartment was 25 per cent. lower than that outside. The readings obtained before and after decontamination of the outside of the deckhouse were the same showing that the contamination on the actual deckhouse made only an insignificant contribution to the level of radiation inside.

15.9. *Radiac Instruments*

Tests under service conditions were made of many types of dose-rate meter and personal dosimeters. A report on appropriate ones has been made to the Radiac Panel.

TABLE 15.1

Contents of Food Dumps

Commodity	Weight	Container
Flour	3 × 140 lb. bags	Finely-woven jute
	3 × 140 lb. bags	Cotton
	3 × 140 lb. bags	Nylon
	2 × 56 lb. bags	5-ply paper, bitumen-lined
Wheat	5 × 180 lb. sacks	Jute
	3 × 180 lb. sacks	Cotton
	2 × 56 lb. bags	Paper, 5-ply, bitumen-lined
	2 × 56 lb. bags	Paper, no lining
Carcase Meat ...	1 Carcase of mutton, total weight 50 lb. ...	Wrapped in cotton
Sugar	1 × 160 lb. sack	Jute
	1 × 160 lb. sack	Cotton
	1 × 56 lb. case containing 28 × 2 lb. cartons	Fibreboard
	28 × 2 lb. cartons	Cardboard, unwrapped
Tea	1 × 120 lb. chest	Plywood—metal foil-lined
	56 × ½ lb. packets	Paper, no outer wrapping
Canned Meat ...	24 × 6 lb. tins (360 lb. gross)	
Fats	1 × 64 lb. cases	Wood—paper-lined
	28 × ½ lb. packs	Paper—exposed
	28 × ½ lb. packs	Paper inner—fibreboard outer
Rice	2 × 114 lb. bags	Jute
	1 × 114 lb. bags	Cotton
Potatoes ...	2 × 1 cwt.	Jute sacks
	2 cwts.	Buried in soil
Cabbage ...	1 cwt. (2 × 56 lb.)	String bags

16. BIOLOGICAL INVESTIGATIONS

16.1. *Introduction*

Previous atomic explosions have provided information about injuries from blast effects, heat and prompt nuclear radiations, but relatively few data are available about the biological hazards of fall-out. The purposes of these investigations, undertaken at the instance of the Medical Research Council, were therefore to observe the Monte Bello explosion from the point of view of all medical effects, in a general way, and to scrutinise those of the fall-out in particular.

The following questions were selected for special study:—

(*a*) Would radio-iodine exist in the *fall-out on the ground* or in a vapour state? The absence of radio-iodine would not only influence ground radiation doses by some 20 per cent. in the first few days, but also the rate of decay of fall-out at this time.

(*b*) Would the iron and debris present during the quenching of the fire ball absorb the fission products and interfere with their availability to plants and animals? This would influence all risks due to radio-active elements lodging in tissues, especially bone, after inhalation or swallowing fall-out.

Investigations were conducted at the trial, and later in laboratories in the United Kingdom. In particular, samples of fission products were collected after the explosion and flown back to the United Kingdom for plant and animal studies.

16.2. *Studies in Relation to Operational Problems*

16.2.1. *Availability and Absorption of Radio-elements by Biological Systems*

Various animals and fish were caught within seven days of the explosion. Radio-iodine was recognised in the thyroid of a severely contaminated rat. The radioactive decay of all other tissues examined, including bones, suggested the absorption of a diversity of radio-elements by biological systems. Radio-iodine also appeared to be available to, and concentrated by, seaweed in the lagoon.

These results indicated that previous assumptions about the constitution of the mixed fission products on the ground are applicable to calculations of the intensity of radiation fields and their decay rates there in the early days after the explosion. The absorption of radio-iodine and other fission products revealed that the presence of iron and debris had not completely eliminated biological hazards due to swallowing or inhaling them and made necessary the quantitative studies of uptake described in Sections II and III below, and more experiments at the trial.

16.2.2. *Contamination and Decontamination of Vegetation*

It was found that the radioactive contamination of leaves was particulate, and, in worst cases, it could be recognised as black spots, visible to the naked eye; this could be of assistance to radiological monitors.

As up to 66 per cent. of the radioactive contamination could be removed by washing vegetation for 10 minutes, some measure of salvage of vegetables might be achieved, and such washing would be worth while in the absence of radiological monitoring, or until this could be completed. There appeared to be very little selection of the radio-elements removed from vegetation by water or detergents. Heavy rain cannot be expected to effect the complete decontamination of the surface of vegetation. A rough estimate suggests that 60–90 per cent. would be removed by heavy precipitation. Radio-elements from the fall-out, blackened with debris, which fell to the North of the Target Vessel, were absorbed by plants and recognised in leaf veins. However, this internal contamination was small by comparison with that adhering to the surface of leaves.

16.2.3. *Inhalation of Fission Products by Human Beings*

Inhalation could be another route of entry for fission products into animals and man. At various times, men entered the radioactive areas without respirators and it was possible to find traces of radioactivity in their urine within a few days. In an experiment designed to utilise a situation which arose fortuitously, it was possible to secure convincing evidence that such radioactivity in urine had been due to the inhalation of fission products, rather than by other possible routes of entry. These, and other, results indicated that respirators were effective barriers against the inhalation of fission products from this atomic weapon.

The amounts of radioactivity found in the urine subjects collected for 30 hours after exposure without respirators ranged up to 25×10^{-3} microcuries. These small amounts had some rough correlation with the radiation dose from the fission products on the ground. These results were in general agreement with previous predictions as between the uptake by inhalation, and the surface radiation intensity. Although only traces of radioactivity were found in men exposed to the fall-out several days after the explosion, it would seem advisable to wear a respirator while the fall-out settled.

It may be of some operational significance to record that, as expected, the urine of a man who inadvertantly bathed in and swallowed mildly contaminated water (2 milli-r/hr at 3 feet) did not contain measurable radioactivity.

16.2.4. *Protective Clothing: Thermal Stress*

Men working in radioactive areas wore dark-coloured protective garments. The first parties to return to the Health Ship on D-day showed many features of thermal stress including intense thirst, marked irritability and tremor. Investigations were initiated. Men wearing the protective clothing in solar radiation with wind speeds of 9–10 knots, shade temperature of 77–86° F. and Relative Humidities of 61, lost up to 16 lbs. The mean 4-hour sweat rates ranged from 2–4 litres on various days. A sweat rate of 4 litres per hour is approximately the general upper limit of tolerance. It is concluded that the thermal stress of protective clothing deserves consideration.

16.2.5. *Decontamination Procedures—Time Involved*

After returning from radioactive areas, all men were monitored, decontaminated by washing and remonitored. The average times taken for the various procedures were measured, as follows:—

(*a*) Being undressed down to underwear and socks ...	61	seconds
(*b*) Preliminary monitoring	169	„
(*c*) Showering	390	„
(*d*) Drying	126	„
(*e*) Second Monitoring	164	„

In the case of personnel still contaminated—

(*f*) Application of decontaminating chemicals	60	„
(*g*) Second shower—usually to neck	235	„
(*h*) Second drying	120	„

Some men needed 5 showers to pass the (very low) tolerance at final monitoring.

These times do not include waiting periods. It must be emphasised that they apply to men insulated by protective clothing. The times would be greater for uninjured persons not in protective clothing escaping after an attack. It is clear that great time losses would accrue in the general confusion whether such persons were left to fend for themselves, or if cleansing were organised. Decontamination would certainly have to be organised for all casualties, with ensuing delays in evacuation, sorting and treating them.

16.3. *Botanical Investigations of Material Collected at Monte Bello*

16.3.1. *Introduction*

The objects of the investigations were:—

(*a*) To make some measure of the degree of contamination of the ground by radio-elements of biological significance.
(*b*) To discover the fraction of the deposited radioactivity which consisted of such radio-elements.
(*c*) To determine the extent to which such radio-elements were available to plants.
(*d*) To discover how various soils might influence this availability.
(*e*) To assess the effect of rain upon the movement of fission products into the soil.

16.3.2. *Materials Used in these Investigations*

The materials which became available for study were:—

(*a*) Esparto grass filters contaminated with airborne fission products.
(*b*) Cotton gauze sheets, 1 yard square, collected from T 2 on D + 3.
(*c*) Miscellaneous plant samples collected from Gardenia, Primrose, North East and Trimouille Islands within three weeks of the explosion.

These materials became available in the United Kingdom 9, 13 and 48 days after the explosion. The majority of tests were conducted with aqueous extracts of the filters and the cotton gauze sheets, neither of which were contaminated by the blackened fall-out. However, it should be pointed out that it is highly unlikely that practical agriculture would be considered soon after an attack in areas visibly contaminated. The long-term problems in such an area are under study.

16.3.3. *Degree of Radioactive Contamination of the Ground*

The mean contamination levels by radio-elements of biological significance on the cotton gauze samples examined were, as microcuries per cm.^{2}, ^{140}Barium: 0·89, ^{89}Strontium: 0·007, ^{131}Iodine: 0·99, ^{106}Ruthenium: 0·013. All these values have been extrapolated back to the day of the explosion, at which time they exceed the levels judged to be tolerable for cattle grazing by factors of 10 to 2,000.

16.3.4. *The Fraction of Total Radioactivity on the Ground which Consisted of Radio-elements of Biological Significance*

The solubility of fission products in water and aqueous carrier solution was regarded as a useful index of biological significance. 60 per cent. of the total activity in the cotton gauze samples, and 80 per cent. of that in the esparto grass filters, were soluble in this way.

Analysis of the radio-elements in these solutions several weeks after the explosion revealed that, as calculated back to the day of the explosion, ^{131}Iodine was predominant and ^{140}Barium, ^{89}Strontium and ^{106}Ruthenium were also present: the proportions were approximately 600 : 175 : 15 : 3, respectively. Traces of other Rare Earths were also identified.

16.3.5. *Absorption of Radio-elements by Plants*

The absorption of the radio-elements in an aqueous extract of cotton gauze was studied.

(*a*) *Water Culture.*—Barley and cabbage were grown in the aqueous extracts, alone and with various nutrients and concentrations of calcium ions. In 12 days, Barley took up 20 per cent. of the radio-barium present, 10 per cent. of the radio-strontium, 12 per cent. of the radio-iodine and 8 per cent. of the radio-ruthenium from the aqueous extract alone. Cabbage took up rather less ruthenium and rather more of the other radio-elements studied. After 21 days, the uptake was somewhat increased. Smaller amounts of barium and strontium were absorbed in the presence of calcium ions. It may also be noted that very little of the ruthenium or iodine was transferred from the roots to the shoots.

(*b*) *Soil Culture.*—Wheat was grown in soil from Wytham and Cannock Chase to which aqueous extracts of the contaminated gauzes had been added. After 150 days, the radioactive content of the whole plants was less than 1 per cent. of the total activity added, and probably less than 0·5 per cent. of the original total fission products in the gauze. The radioactivity in the wheat shoot was greater by a factor of 3, in those growing in Cannock Chase soil. This is believed to be related to the lower calcium content of this soil, 0·6 mEq. per cent. as opposed to 17·2 mEq. per cent. in the case of Wytham soil.

Important for future laboratory studies is the finding in parallel experiments that the absorption and behaviour of carrier-free ^{90}Sr was in every way similar to the same element in the mixed fission products.

16.3.6. *The Effect of Rain upon the Movement of Fission Products into Soil*

One hundred days after the explosion, aqueous extract of fission products was added to the surface of soils in 12-inch high cylinders, and the mixture exposed to natural rainfall for a further 80 days.

Eighty-eight per cent. of these soluble fission products were retained in the top 1 inch of the Wytham soil, and 68 per cent. in the top 1 inch of the Cannock Chase soil.

Of the traces of radioactive material leached through the 12 inches of soil, over 90 per cent. was as ^{106}Ruthenium, which therefore may be regarded as the radio-element most likely to migrate from contaminated areas into the water table and so drain away.

16.3.7. *Summary of Botanical Investigation*

The results show that after the Monte Bello explosion, contamination of the ground occurred which was at dangerous levels for agriculture in places where the fall-out was not visible to the naked eye.

The presence on the ground of radio-iodine, and other radio-elements of biological importance, was confirmed, as was their availability to plants. However, apart from the risks of animals and human beings eating vegetation contaminated directly on the surface, a variety of factors in Nature tended to diminish the risks to be expected from eating fresh crops of vegetation growing in the fall-out area after the Monte Bello explosion.

Sixty per cent. of the fission products which lay invisible on the ground in the highly contaminated region of Trimouille were soluble, and may be considered as of biological significance. Although plants growing in water culture might take up as much as 50 per cent. of these soluble fission products in 21 days, in the more practical experiments, wheat shoots grown for 150 days in soil to which soluble fission products had been added contained less than 1 per cent. of the radioactivity applied (*i.e.*, about 0·5 per cent. of the total fission products). This low fraction of fission products absorbed may be related to the fact that almost all the fission products were trapped in the top inch of soil, even after exposure to rain for 80 days. Thus the percentage uptake might be higher with shallow-rooted plants such as grass.

The retention of fission products in the upper layers of soil precludes their rapid removal from contaminated areas by rain. Less than 5 per cent. of the fission products were leached through 12 inches of soil between D+120 and D+200. Ruthenium constituted most of this leached fraction. Fortunately Ruthenium was not absorbed readily by plants; less than 1 per cent. of ^{106}Ruthenium in water cultures found its way into the shoots of barley and cabbage plants growing therein for 12 days.

These results agree with the findings at the trial that internal contamination in plants is much less than direct surface contamination. Under the conditions of these experiments the expected uptake of fission products by new crops growing in contaminated soil would be no higher than 1 per cent., and new crops growing in areas draining contaminated zones, probably less than 0·05 per cent. More investigations are needed before these data can be used to determine accurate safety levels. In particular, it is necessary to establish the percentage of radioactivity in plants which can be absorbed by animals and man as a result of ingesting crops containing such radio-elements as the latter will select from the soil.

These investigations are being pursued.

16.4. *Zoological Investigations with Material Collected at Monte Bello*

16.4.1. *Introduction*

The purpose of these investigations was to confirm and extend, both qualitatively and quantitatively, those made on animals at the trial. Particular attention was paid to the proportion and chemical identification of fission products taken up by various tissues.

16.4.2. *Materials and Methods*

The samples investigated were:—

(*a*) Airborne fission products collected on esparto grass filters. These and aqueous extracts thereof were fed to 4 rabbits 200–859 hours after the explosion.

(*b*) Aqueous extracts of " invisible " fall-out from T 2 on Trimouille as prepared for the botanical experiments, containing 15–20 per cent. of the total radioactivity present in the fall-out. This was fed by pipette to 11 guinea-pigs 200–400 hours after the event.

(*c*) Blackened earth and sedge-like herbage collected inland from Main Beach on Trimouille. These, and aqueous extracts thereof, were fed to guinea-pigs and 6 rabbits 1,300–2,500 hours after the event.

The animals were sacrificed at various times after being fed, dissected, and digests prepared of excreta, intestines, muscles, liver, kidneys, thyroid, and bones. These digests were investigated in an M.6.H. liquid counter.

16.4.3. *Results of Examining Tissue Digests for Radioactivity*

(*a*) *General.*—Computations comparing the total radioactivity given to that detected in the excreta and tissues showed that recovery was within the limits of the errors in methods of feeding. A large proportion (usually more than 50 per cent.) of the radioactivity given appeared in the fæces and bowel contents and a small percentage was detected in the urine. The findings in all tissues except the thyroid and bones were of more interest than practical significance: after early sacrifice the livers, kidneys and muscles contained small percentages of relatively rapidly decaying fission products.

More detailed investigations were directed towards the findings in the thyroid gland, the skeleton, the former because of its value in providing information about radioactive iodine, the latter because of the clinical importance of injury to the blood-forming cells from bone-seeking fission products.

(*b*) *Thyroids.*—Up to 2·4 per cent. of the radioactivity in the samples fed within 2 weeks of the explosion could be traced in the thyroid gland.

On D + 10 the thyroid from an animal fed with airborne fission products showed a decay compatible with a mixture of ^{132}I and ^{131}I. The decay of other thyroid glands was always with an 8 day half life. presumably due to ^{131}I.

15–20 per cent. of the radio-iodine in the aqueous extracts of invisible fall-out from T 2 fed to animals could be found in their thyroids after 24 hours.

It was therefore concluded that radio-iodine was present not only in the airborne cloud, but also in the *invisible* fall-out, and that it was water soluble and available for absorption by guinea-pigs and rabbits; it did not prove feasible to investigate the presence and availability of radio-iodine in the *black* fall-out.

(*c*) *Bones.*—The outstanding feature of these studies was the variation in the percentage of radio-activity deposited in the bones after feeding different samples of fission products. The average percentages were:—

Airborne Fission Products	8 per cent.
Aqueous Extracts of Invisible Fall-out	14 per cent., *i.e.*, some 3 per cent. of the total activity on the ground.
Blackened Fall-out ...	0·2 per cent.

The counts of all skeletal digests showed an early rise, which could be attributed to ^{140}Lanthanum being formed from ^{140}Barium. The subsequent decay could have been explained by various mixtures of ^{140}Ba and ^{89}Sr, but chemical analysis revealed the presence of various Rare Earths as well: Cerium, Yttrium and Praseodymium have been identified.

More detailed studies showed that, after feeding airborne fission products and aqueous extract of invisible fall-out, the proportion of Barium and Strontium in bones was roughly the same as in the material given. In contrast, after feeding material contaminated with blackened fall-out—where the percentage deposition in bone was so small (0·2 per cent.)—the absorption of Barium and Strontium was even more severely curtailed than that of Rare Earths.

16.4.4. *Supplementary Experiments*

The low absorption after feeding blackened fall-out and the very small percentage deposition in skeletons are obviously of interest not only in respect of a possible atomic attack, but also in the event of accidental exposures to mixed fission products in atomic energy programmes.

Some possible factors responsible for the diminished deposition in bones are as follows:—

(*a*) The presence of Magnesium Sulphate in the Monte Bello sand.
(*b*) The presence of Calcium ions in the Monte Bello sand; both these facts were known from previous soil analysis.
(*c*) The presence of iron from the target vessel.

Because low absorption was found using black fall-out but absent using extracts of the invisible fall-out which was mixed with Monte Bello sand at T 2, interest was naturally aroused in the possible rôle of iron in interfering with the absorption of Barium and Strontium as well as Rare Earths.

In an experiment with guinea-pigs fed radio-Barium/Lanthanum solution with minimal carrier, it was shown that 5 mg. spectroscope-pure Iron oxide half an hour before feeding would reduce deposition in the skeleton by a factor of 3. When the same treatment was also continued twice a day for 3 days after feeding, the deposition in the skeleton was reduced by a factor of 10.

These studies continue.

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ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT No. T 1/53
(HURRICANE)

B. 0134

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BY AWE ALDERMASTON

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A.W.R.E.
Aldermaston Berks.

[redacted]

May, 1953

3.2 Blast Damage

3.2.1 Anderson Shelters

Standard Anderson Shelters, with sandbag covering and blast wall construction were located at 460, 510, 600, 920 and 1,130 yards from ground zero. Mean blast pressures, in pounds/sq. inch, recorded inside the shelters are shown in the following table.

Distance (yds.)	Presentation		
	Front	Side	Rear
460	NR	NR	NR
510	38	27	40
600	28	21	28
920	16	7	14
1130	8.5	4	5.5

Front presentation implies blast wall facing towards event.
Rear " " " " " away from event.
Side " " shelter side on to event.

Shelters at 460, 510 and 600 yards suffered damage including demolition of blast walls, removal of sandbag covering and some displacement of the corrugated iron.

At 920 and 1,130 yards the shelters suffered relatively little damage.

Civil defence authorities consider that there might have been some 50% survival from blast damage of personnel in shelters at 460 yards and some 90 per cent at 600 yards, fatal casualties being mainly due to secondary blast effects (e.g. debris) and not to direct effects on the person of the blast pressure itself. The front presentation appears the most hazardous, due to the collapse of the blast wall into the shelter. At such distances, however, the survival from the effects of gamma flash would have been virtually nil. (MORE EARTH COVER IS NEEDED FOR RADIATION.)

At 920 and 1,130 yards there would have been no casualties from blast, and incidentally, little risk from the effect of gamma flash.

3.2.2 Concrete Cubicles

Reinforced concrete cubicles, 12 feet cube were exposed to the blast. There were three types of cubicle, varying in wall thickness and the mesh of reinforcement. The following table gives some details:-

Thickness of Wall and Roof	Mesh of Reinforcement		Dia. of Rods (mild steel)
	Walls	Roof	
$6\frac{3}{4}$"	9"	$7\frac{1}{2}$"	$\frac{5}{8}$"
$9\frac{3}{4}$"	$6\frac{1}{2}$"	$4\frac{1}{2}$"	$\frac{3}{8}$"
12"	9"	$5\frac{1}{2}$"	$\frac{3}{8}$"

The concrete was a mixture of 1 cement, 1.4 sand and 2.8 of $1\frac{1}{4}$ inches aggregate (parts by volume). The aggregate was of local rock and rather soft and weak. The water/cement ratio was 0.5. This produced a crushing strength of 6 inches cubes of over 2,000 p.s.i. in 7 days.

The cubicles faced the event squarely. In the rear wall was a tapered opening about 2 feet high × 1 foot 6 inches broad into which a pile of four tapered blocks fitted to close this entrance prior to the explosion.

A $9\frac{3}{4}$ inch wall thickness cubicle was 600 yards from the explosion. Its front wall failed and was pushed inside the cubicle. The side walls were fractured and had a slight outward bowing (about 1 inch). The rear wall had minor hair cracks. The roof showed cracks along the line of the inside of the side walls and had failed completely along the line of the front wall.

At 990 yards, $6\frac{3}{4}$ inch and $9\frac{3}{4}$ inch walled cubicles showed fine hair cracks. There was no damage to the 12 inch walled cubicle at this distance, nor to one with a $9\frac{3}{4}$ inch wall at 1,320 yards.

In all cases the tapered blocks closing the rear entrance had been thrown outwards.

4. Water Shock

The underwater shock was relatively feeble, and significant recordings were obtained at two points only. The results were:-

Depth of gauges - 22 feet.

Distance from weapon (feet)	Pressure p.s.i.
960	270
1185	20
1380	~ 0

Compare to air blast peak overpressures.

6. Fires

Some outbreaks of fire took place amongst the parched grass-like vegetation on Trimouille. It appeared that these were not due to radiant heat from the weapon, but arose from ignition by hot fragments of H.M.S. Plym. The inference is that the water column formed an effective shield against the direct thermal effects of the radiation.

7. The Gamma Flash

7.1 The Dose - Distance Relationship

The decay of short lived fission products from the weapon gives rise to an intense pulse of gamma radiation. A large proportion of the dose from this is received in a few seconds. Figure 4 shows the total dose (recorded by films) as a function of distance from the weapon.

7.2 Gamma Energies

In applying these results to shielding problems (using for example the methods given by Liston and Cave, HER Report H13/51) it would be desirable to know what assumed energy of photon would give the right answer. Naturally, the actual gamma ray flux consists of a continuous spectrum of a quite unpredictable nature.

The spectrum will of course vary with the distance from the weapon, largely due to Compton scatter. No data are available from the trial which can lead to an estimation of these spectra. The trend of the dose distance curve is similar to that which would be calculated on the assumption that the original photons were all of about 3 Mev energy; one must be careful not to draw any further conclusions from this statement.

Concrete cubicles of wall thickness $6\frac{3}{4}$ inches, $9\frac{3}{4}$ inches and 12 inches at 900 yards appeared, from somewhat incomplete data, to give the same reduction of dose inside as they would from a parallel gamma beam of about 1 Mev photons. At 1,320 yards a cubicle with a $9\frac{3}{4}$ inch wall appeared to reduce the dose by an amount equivalent to the reduction expected from a parallel $1\frac{1}{2}$ Mev beam. This latter result implies an energy higher than $1\frac{1}{2}$ Mev at 900 yards, and does not appear to be consistent with a value of 1 Mev at 900 yards. The difference between the results might be within the errors inherent in experiment and calculation.

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3 OCTOBER 1963

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RESEARCH ON BLAST EFFECTS IN TUNNELS

With Special Reference to the Use of London Tubes as Shelter

by F. H. Pavry

Summary and Conclusions

The use of the London tube railways as shelter from nuclear weapons raises many problems, and considerable discussion of some aspects has taken place from time to time. But - until the results of the research here described were available - no one was able to say with any certainty whether the tubes would provide relatively safe shelter or not.

This research, consisting of a series of model experiments, has demonstrated that the risk from blast in the tubes would be less than the risks above ground. The results are considered to be consistent enough to provide a good estimate of full-scale conditions, and reliable enough to be used as a basis for Home Office shelter policy regarding the London tube railways.

Introduction

When the Advisory Group on Structural Research for Civil Defence was formed in 1957, the Chairman recommended that a study of the effects of blast on tunnels should be one of the main research projects. The relevant paragraphs of his proposals(1) for a research programme were:-

> "In any consideration of tunnels as shelter the crucial problem is the entry of blast, either through existing openings or from a crater formed by a ground-burst bomb. It is particularly important to know if the collapse of a tunnel by earth shock would prevent the blast from entering it, and also whether the collapse would provide a seal against the entry of water from the crater. It is probable that some data could be derived from model experiments using H.E. charges. But it is for consideration whether the results would be so conclusive that the behaviour of full-size tunnels when damaged by megaton weapons could be forecast with the confidence that a major shelter programme would demand."

At the second meeting(2) the Group agreed that model experiments with H.E. charges would be worthwhile, and that the Atomic Weapons Research Establishment (A.W.R.E.) should carry out this research, which has now been accepted by the Advisory Group as successfully completed. A summary record of the progress follows.

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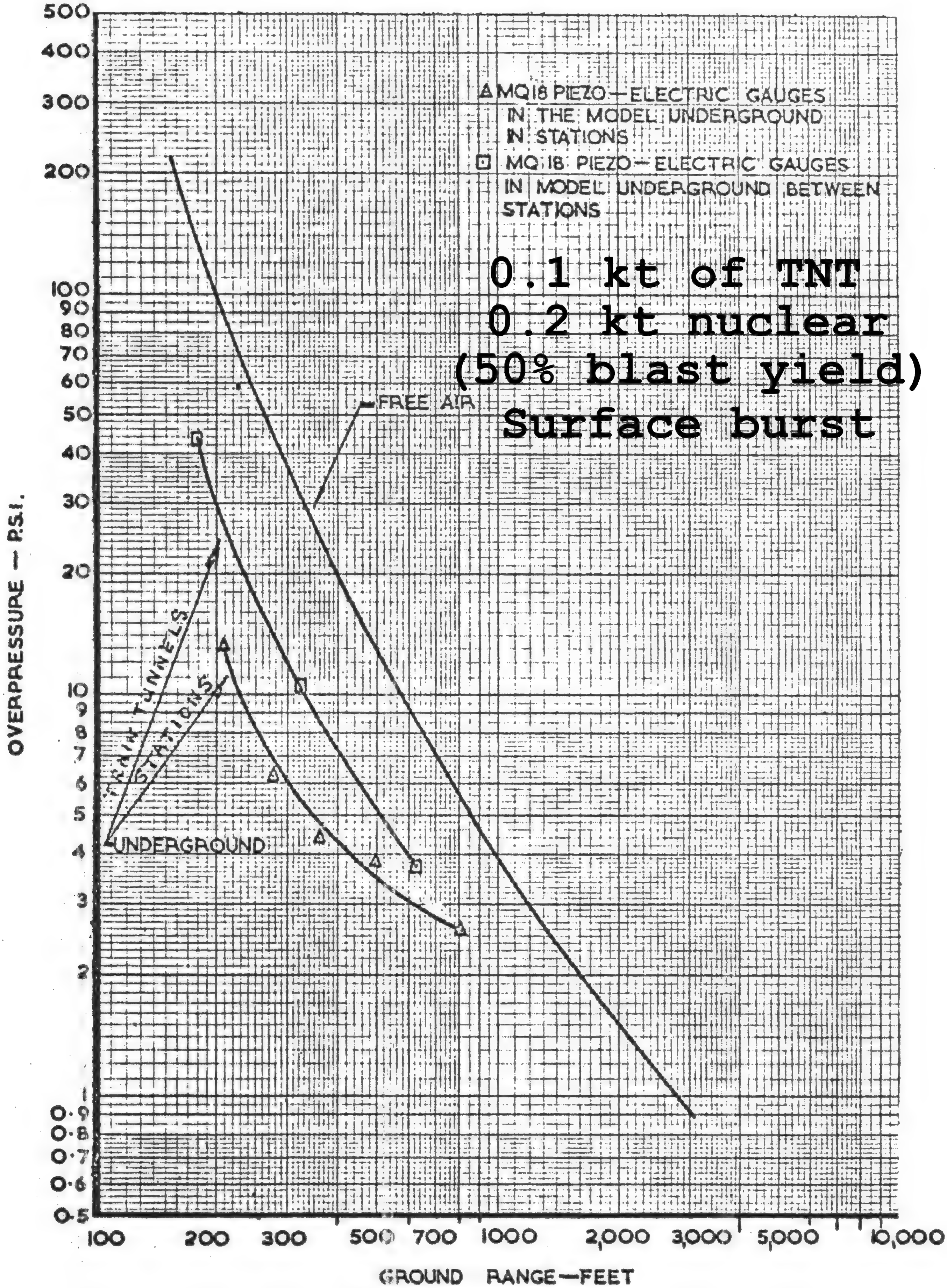
100 ton TNT test on 1000 ft section of London Underground tube at Suffield, Alberta, 3 Aug 1961



Atomic Weapons Research Establishment, "1/40th Scale Experiment to Assess the Effect of Nuclear Blast on the London Underground System", Report AWRE-E2/62, 1962, Figure 30. (National Archives ES 3/57.)

These trials are described in a preliminary report[5] prepared for the Advisory Group by A.W.R.E. It was shown that the blast pressure inside a tunnel system, having openings at intervals to ground level, is less than the pressure at ground level at any distance from the explosion, by a factor of about 3. This reduction in pressure was apparently caused by the station entrances acting as expansion chambers. This observation was of outstanding significance to the consideration of London tubes as shelter.

All previous research on blast in tunnels - and a great amount of work was done on this in the last war - had been conducted with blast entering the open end of a tunnel without side openings. This research had shown that the blast, once it had got into a tunnel, tended to travel great distances without appreciable diminution. This had, therefore, led to the general belief that the London tubes could be death traps rather than shelters.

The more recent research here described showed for the first time that a person sheltering in a tube would be exposed to a blast pressure only about $\frac{1}{3}$ as great as he would be exposed to if he was above ground. (In addition, of course, he would be fully protected from fallout in the tube.)

In fact A.W.R.E. carried out two further tests, with more accurate scaling of station volumes based on more detailed information from the London Transport Executive. A full report on all four tests is in preparation.

These later tests showed that the pressure in station tunnels was only about 1/6th of the ground-level pressure, but that the reduction was not so great in the smaller-diameter train tunnels.

At this stage the Advisory Group were reasonably satisfied that this problem - of blast entry from stations - had been solved. But the other major question of blast entry direct from the crater remained in doubt, on account of the very small scale of the tests to date. Therefore, when the opportunity arose of testing at a really large scale at Suffield, Canada, it was naturally accepted.

Large-Scale Field Test (1/40) at Suffield, Alberta

The test is fully described in an A.W.R.E. report[6]. The decision of the Canadian Defence Research Board to explode very large amounts of high explosive provided a medium for a variety of target-response trials that was welcome at a time when nuclear tests in Australia were suspended. A.W.R.E. used the 100-ton explosion in 1961 to test, among other items, the model length of the London tube, at 1/40th scale, that had already been tested at 1/117 scale.

Blast Entry from Stations

There was remarkable agreement with the 1/117th scale trials: "maximum overpressure in the train tunnels was of the order of $\frac{1}{3}$rd the corresponding peak shock overpressure in the incident blast. The pressures in the stations were about 1/6th those in the corresponding incident blast .... ". In comparing the results at the two scales it was noted that the pressures in the train tunnels (between stations) was higher at Suffield than at the smaller scale; this may, the report suggests, have been due to some blast entry from the crater at Suffield.

Blast Entry from the Crater

There may - as has just been noted - have been some entry of blast at the crater. But the all-important fact is that it was nowhere enough to bring the pressure in the tunnel up to more than a $\frac{1}{3}$rd of the free-air pressure (see fig. 30 reproduced, and attached to this note.) From this, and from a detailed study of tunnel rings ejected by the explosion over a wide area, it can be concluded that the instantaneous crushing of the tube near the crater sealed it against the entry of any significant blast pressure.

Air Flow in Stations

The Report indicates that there would be turbulence generated by blast entry at stations and that there would be a danger to occupants there, on account of blast "windage" acting on them and on missiles that could injure them. This danger would be less in the train tunnels between stations.

Conclusion

The Advisory Group discussed the Suffield Test on tunnels on Nov. 1st 1962, and concluded that model experiments have successfully demonstrated that the risks from blast inside the London tubes would be less than above ground. The Group considered that the results obtained were consistent enough to provide as good an estimate of full-scale effects from megaton weapons as was likely to be obtainable, and that the Chairman could advise the Home Office confidently on the basis of these results. The Group accepted that there would be a risk of casualty-producing air flow in stations, but decided to defer a decision on whether further research on this problem would be profitable. The Chairman said that he would first convey the results of the completed research to the Shelter Division of the Home Office before asking the Group whether it was worth studying this remaining, but less important, problem.

3rd October, 1963.

References

(1) Advisory Group on Structural Research for Civil Defence

Note by Chairman on the Structural Research Programme for Shelters. SAB/SG(57)6. (Restricted)

(2) Notes of Meeting on 15th May 1957. SAB/SG(57)2nd Minutes (Confidential)

(3) The Entry of Air Blast from Craters into Tunnels. A.W.R.E. Report E1/59 (Official Use Only)

(4) The Effect of Tunnel Blockage on Shock Waves .... SAB/SG(58)6 (Confidential)

(5) Model Experiments on the Entry of Blast into the London Underground System, Interim Report on Rounds 1 and 2. SAB/SG(59)4 (Confidential)

(6) 1/40th Scale Experiment to Assess the Effect of Nuclear Blast on the London Underground System. A.W.R.E. Report E2/62. (Official Use Only.)

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MANUAL OF CIVIL DEFENCE

Volume I

PAMPHLET No. 1

NUCLEAR WEAPONS

LONDON
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1956

CONTENTS

30 Research into the causes of fire in Hiroshima and Nagasaki, combined with a study of the secondary fire risk from the flying bomb damage in this country during the last war has shown that with nuclear attack the secondary fire risk is likely to be small compared with the primary risk of direct ignition by thermal radiation.

Fire precautions

31 Although the fire risk even from a nominal bomb is always serious, targets in this country, where the great majority of buildings are of brick, stone or concrete, are less vulnerable to fire than were those in Japan, where most of the buildings were of wood. Moreover, if people do what they can to keep heat radiation out of buildings, the risk of fire can be further reduced, although these precautions would be effective only beyond the central area of blast destruction (see Chapter IV).

32 It might be advisable to brick up certain windows of important buildings, but since the thermal radiation has no great penetrating power, any opaque screen, especially a white one, will keep it out: the simple process of whitewashing windows will keep out about 80 per cent. of the heat. The windows may be broken by the blast wave but as this travels more slowly it arrives after the thermal radiation is over (except of course in the central area of blast destruction), whether the bomb is a hydrogen bomb or an atomic bomb.

33 Another obvious fire precaution is the removal of all readily combustible material from the direct path of any heat radiation that could possibly enter windows or other openings.

34 Both these precautions apply only to those windows and other openings that have a direct view of some part of the sky. In a built-up area they would apply more particularly to the windows of upper floors; even for a high airburst, in a closely built-up area one building shields another to a considerable extent.

The probable fire situation in a British city

35 Within ½ mile of an airburst nominal bomb the heat flash is very intense indeed, but in this area there would be almost complete destruction of buildings by blast, and this would tend to impede the development of fire. This did not happen in Japan because most Japanese houses are constructed of wood and once they were set on fire they continued to burn even when knocked over. In this country only about 10 per cent. of all the material in the average house is combustible, and under conditions of complete collapse, where air would be almost entirely excluded, it is doubtful whether a fire could continue on any vigorous scale. The main fire zone will be around this central area of heavy destruction, in the region where buildings are damaged but standing sufficiently to allow free burning. For a nominal bomb, this zone is likely to reach as far as 1¼ miles.

36 The range of ignition is affected to some extent by the state of the atmosphere and on a dull misty day will be reduced, although it is impossible to say precisely to what degree.

The possibilities of a fire storm

37 The chief feature of a fire storm is the generation of high winds which are drawn into the centre of the fire area to feed the rising column of hot air and flames. These in-rushing winds prevent the spread of fire outwards, but ensure the almost complete destruction by fire of

everything within the fire area. This inevitably increases the number of casualties, since it becomes impossible for people to escape by their own efforts because they succumb to the effects of suffocation and heat stroke.

38 The Hiroshima bomb (but not the Nagasaki one) caused a fire storm. A fire storm occurred in Hamburg and possibly also in several other German cities as a result of accurate and very dense attacks with incendiary and high explosive bombs by the R.A.F. Information on the subject is limited, but it has been fairly well established that during these particular raids on Germany half the buildings in the target area were set on fire in about half an hour. In such circumstances it seems that nothing can prevent all the fires from joining together into one mass fire engulfing the whole area.

39 Whether a fire storm develops depends also on the nature of the target; where there are tall buildings closely packed together with plenty of combustible material to burn, the risk is much greater than in areas less densely built up.

40 It seems unlikely from the evidence available that an initial density of fires equivalent to one in every other building would be started by a nuclear explosion over a British city. Studies have shown that a much smaller proportion of buildings than this would be exposed to thermal radiation and even then it is not certain that continuing fires would develop. Curtains may catch fire, but it does not necessarily follow that they will set light to the room; in the last war it was found that only one incendiary bomb out of every six that hit buildings started a continuing fire. Moreover after a nuclear explosion the large and almost completely flattened central area would counteract the development of a fire storm, since one essential requirement seems to be a continuous mass of fire over a large area. It is unlikely, therefore, that a fire storm would develop after a nuclear attack on a British city, though the possibility cannot be ruled out. The risk can be reduced by clearing or partially clearing the top floors of buildings which are likely to be exposed to the heat radiation, and by adopting the other precautions mentioned above.

41 There would, however, in any case be many serious fires and fire areas.

Scaling laws

42 For more powerful bombs the total heat output is roughly proportional to the power of the bomb, so that a 10 megaton bomb, which is 500 times more powerful than a nominal bomb, radiates 500 times as much heat. Because of the inverse square law, the distance at which a given amount of heat is received (measured per unit area of receiving surface) varies as the square root of the power of the bomb. For example, if a nominal airburst bomb produces 5 calories per square centimetre at 1 mile, a 10 megaton airburst bomb will produce the same amount at 22 miles ($22=\sqrt{500}$). However, although at 1 mile from a nominal bomb an intensity of 5 calories per square centimetre would ignite easily combustible materials and start fires, it would not do so at 22 miles from a 10 megaton bomb because the heat is applied more slowly. From a 10 megaton bomb, with its longer lasting thermal radiation (see paragraph 21), it takes about 20 calories per square centimetre to start fires because so much of the heat (spread out over the longer emission) is wasted by conduction into the interior of the combustible material and by convection and re-radiation whilst the temperature of the surface is being raised to the ignition point. But the distance at which 20 calories per square centimetre can be produced is only 11 miles, so that the scaling factor for a 10 megaton airburst bomb is therefore 11 and not 22.

43 For a ground burst bomb, however, several other factors contribute to a further reduction in the fire range. Apart from an actual loss of heat by absorption into the ground and from the pronounced shielding effect of buildings, the debris from the crater tends to reduce the radiating temperature of the fireball and a greater proportion of the energy is consequently radiated in the infra red region of the spectrum—this proportion being more easily absorbed by the atmosphere. The magnitude of this absorption effect is not known with certainty, but it is important in hydrogen bomb explosions because of the longer ranges involved and because—as later explained in paragraph 81—the likelihood of ground bursts has been increased with the advent of the hydrogen bomb. For all these reasons it has been estimated that the scaling factor for the fire range for a ground burst 10 megaton bomb is about 8. This will mean a fire ring extending from about 3½ to 10 miles instead of, as in the case of a nominal airburst bomb, from ½ to 1¼ miles. Isolated fires may occur at greater distances, depending on the combustibility of material within buildings, but it is impossible to apply precise scaling laws to such haphazard incidents.

44 An important point in relation to personal protection against the effects of hydrogen bomb explosions is that because the thermal radiation lasts so long there is more time for people who may be caught in the open, and who may be well beyond the range of serious danger from blast, to rush to cover and so escape some part of the exposure. For example, people in the open might receive second degree burns (blistering) on exposed skin at a range of 16 miles from a 10 megaton ground burst bomb (8×2—see paragraph 24). If, however, they could take cover in a few seconds they would escape this damage. Moreover, at this range the blast wave would not arrive for another minute and a half so that any effects due to the blast in the open (e.g. flying glass, etc.) could be completely avoided.

Practical protection

88 Large buildings with a number of storeys, especially if they are of heavy construction, provide much better protection than small single-storey structures (see Figure 4). Houses in terraces likewise provide much better protection than isolated houses because of the shielding effect of neighbouring houses.

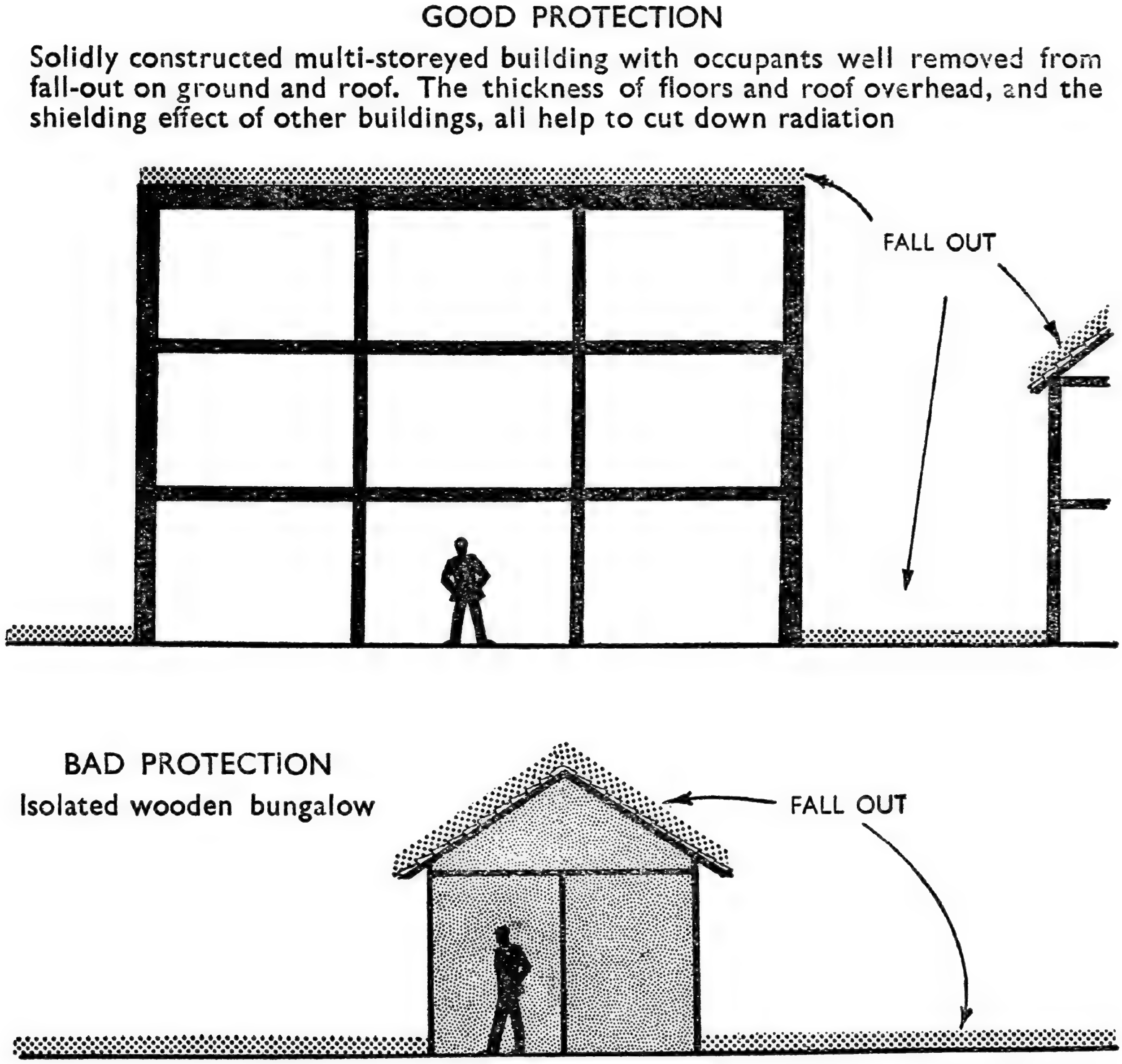


FIGURE 4

Examples of good and bad protection afforded by buildings against fall-out.

89 It is estimated that the protection factor (the factor by which the outside dose has to be divided to get the inside dose) of a ground floor room in a two-storey house ranges from 10 to about 50, depending on wall thickness and the shielding afforded by neighbouring buildings. The corresponding figures for bungalows are about 10–20, and for three-storey houses about 15–100. An average two-storey brick house in a built-up area gives a factor of 40, but basements, where the radiation from outside the house is attenuated by a very great thickness of earth, have protection factors ranging up to 200–300. A slit trench with even a light cover of boards or corrugated iron without earth overhead gives a factor of 7, and if 1 ft. of earth cover is added the factor rises to 100. If the trench can be covered with 2 or 3 feet of earth then a factor of more than 200–300 can be obtained (see Figure 5).

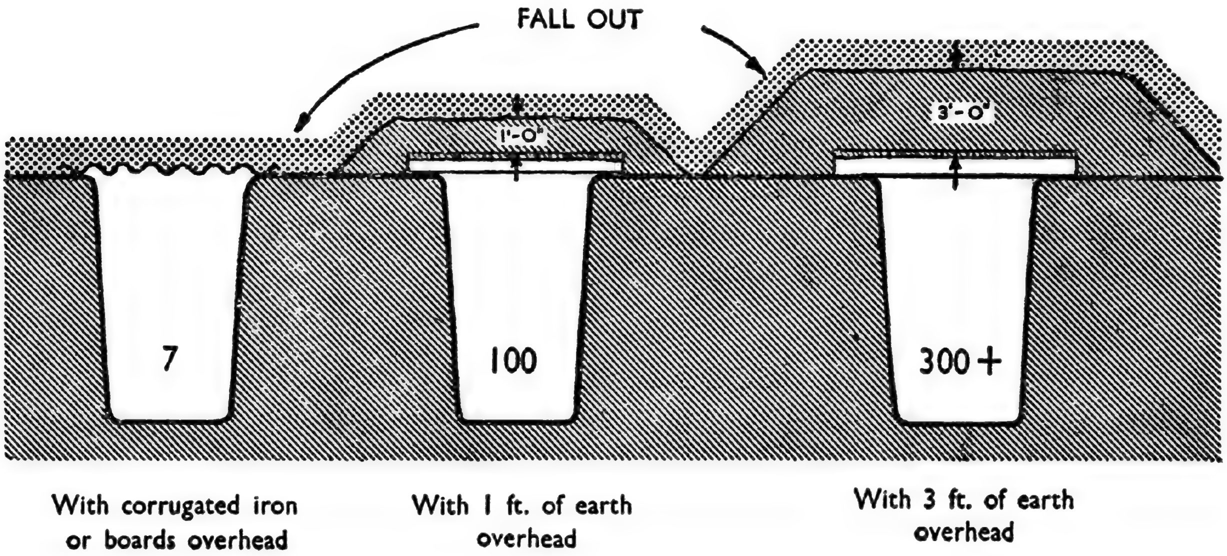


FIGURE 5
Protection factors in slit trenches (the factor by which the outside dose is divided to get the inside dose).

Choosing a refuge room

90 In choosing a refuge room in a house one would select a room with a minimum of outside walls and make every effort to improve the protection of such outside walls as there were. In particular the windows would have to be blocked up, e.g. with sandbags. Where possible, boxes of earth could be placed round an outside wall to provide additional protection, and heavy furniture (pianos, bookcases etc.) along the inside of the wall would also help. A cellar would be ideal. Where the ground floor of the house consists of boards and timber joists carried on sleeper walls it may be possible to combine the high protection of the slit trench with some of the comforts of the refuge room by constructing a trench under the floor.
Once a trap door had been cut in the floor boards and joists and the trench had been dug, there would be no further interference with the peace-time use of the room.

Estimated under-cover doses in the fall-out area

91 Taking an average protective factor of 40 for a two-storey house in a built-up area, the doses accumulated in 36 hours for the ranges referred to in the U.S. Atomic Energy Commission Report (paragraph 84) would have been:—

190 miles downwind	$7\frac{1}{2}$r	15 Megatons
160 ,, ,,	$12\frac{1}{2}$r	Bravo 1954
140 ,, ,,	20r	

which are all well below the lowest figure of 25r referred to in Table 1. At closer ranges along the axis of the fall-out, the doses accumulated in 36 hours would have been much higher, but over most of the contaminated area—with this standard of protection—the majority of those affected would have been saved from death, and even from sickness, by taking cover continuously for the first 36 hours.

5. Radiation sickness

Assume dose incurred in a single shift (3–4 hours) by the "average" man, over the whole body:—

25 roentgens	—No obvious harm.
100 ,,	—Some nausea and vomiting.
500 ,,	—Lethal to about 50 per cent. people (death up to 6 weeks later).
800 ,, or more	—Lethal to all (death up to 6 weeks later).

Note: If dose spread uniformly over 2–3 days, then 60 roentgens could be incurred with no more effect than 25 roentgens in a single exposure of 3–4 hours.

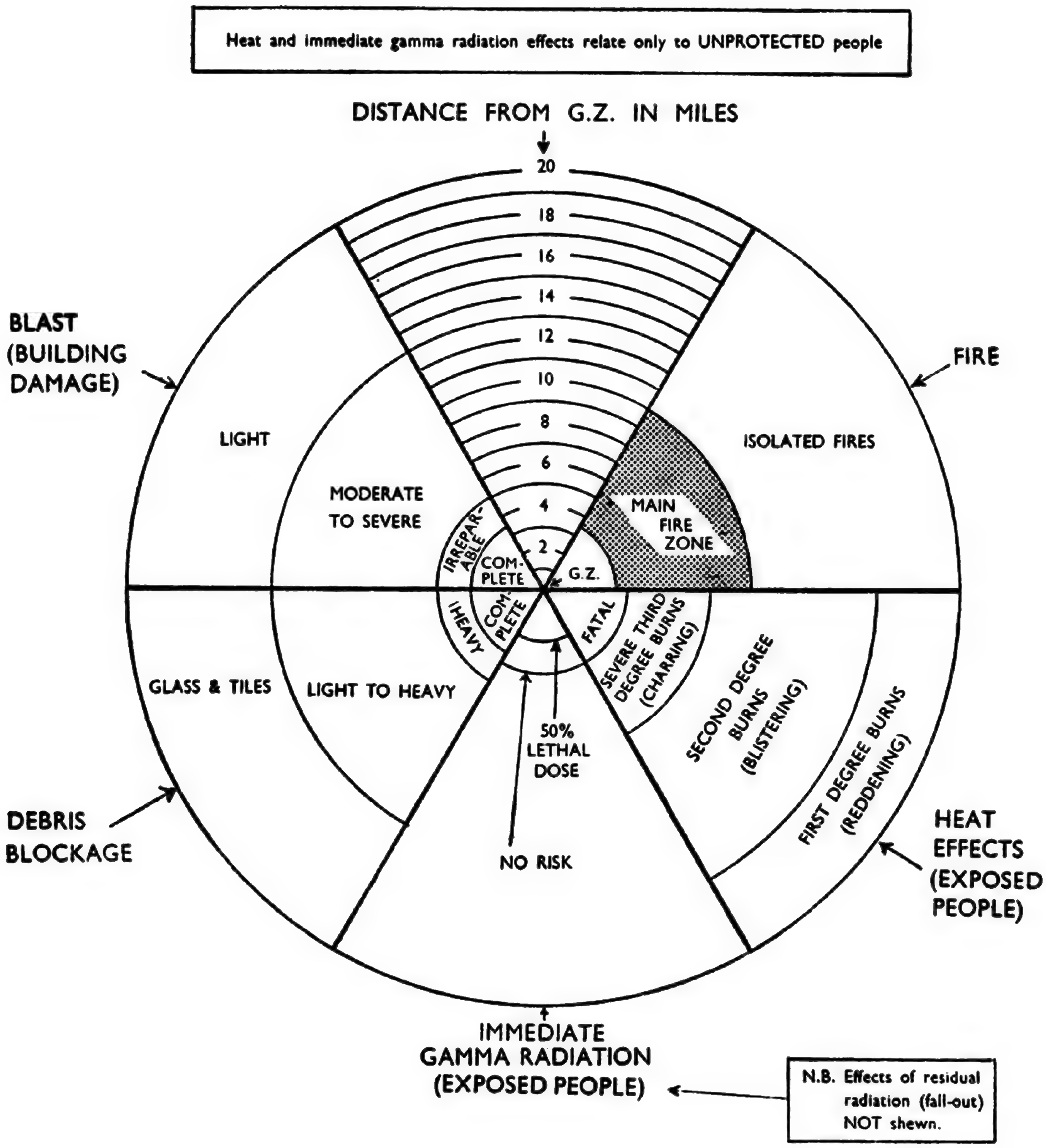


FIGURE 11

Combined effects (excluding residual radioactivity) from a 10 megaton ground burst bomb. Heat and immediate gamma radiation effects relate only to UNPROTECTED people.

A Fallout Forecasting Technique With Results Obtained at the Eniwetok Proving Ground

E. A. Schuert, USNRDL TR-139, United States Naval Radiological Defense Laboratory, San Francisco, Calif.

ADMINISTRATIVE INFORMATION

The work described herein is a part of the research sponsored by BuShips and the United States Army and locally designated as program 2, problem 3, phase 3. Its technical objective is AW-7 and it is described on RDB card NS 081-001.

SUMMARY

The problem: A fallout forecasting technique is needed to qualitatively describe the fallout hazard resulting from nuclear detonations. This technique should have such flexibility that its employment is valid for field use.

Findings: A summary of the latest experimental and theoretical considerations has resulted in the development of a technique whose complexity is dependent on the required accuracy of the results desired. This technique has been satisfactorily tested at the Eniwetok Proving Grounds for land surface and water surface bursts.

Particle size distribution in source model

All particle sizes were assumed at all elevations within the cloud except the lower two-thirds of the stem. However, to obtain agreement with past fallout measurements and with the optical diameter of the mushroom, it was necessary to fractionate the particle size distribution radially within the cloud. Otherwise, the computed fallout area about ground zero would be too large. The fractionation was specified as follows: particles of 1,000 microns in diameter and larger were restricted to the inner 10 percent of the mushroom radius or approximately the stem radius; those from 500 to 1,000 microns in diameter were limited to the inner 50 percent of the cloud radius. Since the relation of activity to particle size is some function of the particle diameter this fractionation tends to concentrate the activity about the axis of symmetry of the cloud.

Falling speeds **(feet/hour)**

J. M. Dallavalle, Mircomeritics, Pittman Publishing Corp., 1948.

Altitude	75 μ	100 μ	200 μ	350 μ	Altitude	75 μ	100 μ	200 μ	350 μ
0	3,060	5,040	11,700	21,600	65	4,190	7,480	26,100	51,100
5	3,120	5,240	12,300	22,900	70	4,110	7,320	27,600	55,200
10	3,200	5,480	12,900	24,100	75	4,010	7,150	28,100	59,700
15	3,270	5,750	13,700	25,500	80	3,910	6,960	27,800	61,900
20	3,360	5,980	14,400	27,100	85	3,800	6,770	27,100	67,800
25	3,470	6,160	15,300	28,800	90	3,720	6,640	26,500	71,300
30	3,570	6,380	16,300	30,800	95	3,620	6,470	25,800	77,300
35	3,720	6,640	17,500	33,000	100	3,550	6,340	25,300	80,200
40	3,870	6,910	18,600	35,300	105	3,470	6,180	24,800	75,800
45	4,040	7,200	19,800	37,800	110	3,400	6,050	24,000	74,200
50	4,210	7,520	21,400	40,600	115	3,330	5,930	23,700	72,600
55	4,420	7,860	23,200	44,600	120	3,260	5,800	23,400	71,100
60	4,200	7,700	24,400	47,200					

Experimental data from past tests at Eniwetok Atoll indicated that the particles were irregular in shape and had a mean density of 2.36 g/cu cm.

Time variation of the winds aloft

In most of the observations made at the Eniwetok Proving Ground, the winds aloft were not in a steady state. Significant changes in the winds aloft were observed in as short a period as 3 hours. This variability was probably due to the fact that proper firing conditions which required winds that would deposit the fallout north of the proving ground, occurred only during an unstable synoptic situation of rather short duration.

The forecasting technique described was employed by the fallout program at the Eniwetok Proving Ground to satisfy certain project requirements. One project had three ships equipped to collect fallout and their positions had to be determined for most efficient collection; another sampled the ocean for fallout; while another made an aerial survey of the contaminated area. The navigational schedules for these latter projects were based on the forecast fallout pattern. Operations were controlled through the program control center aboard the task force command ship where the forecasts were prepared.

The meteorological data was received from the weather ship at Bikini Atoll as well as from weather stations at Rongerik Atoll and Eniwetok Atoll. Furthermore all forecasts made by the task force weather central at Eniwetok Atoll were usually available aboard the command ship by facsimile through the ships weather station.

Upper air measurements were made at Bikini, Rongerik, and Eniwetok Atolls every 3 hours starting at H—24 hour and continuing until H+24 hour for any given detonation. The frequency of observations was usually increased during the period from H—6 to H—2 hours. The altitudes reached on the wind runs were remarkably high and gave perhaps the best set of winds-aloft measurements to date. The average termination altitude was approximately 90,000 feet with many runs over 100,000 feet. Such excellent coverage of the winds aloft was a major help in the fallout forecasting.

Fallout forecasts were made every 3 hours starting at H—24 hour using the *measured* winds available at the time. This process was continued up to shot time and from then on the technique of correcting for time variation was employed every 3 hours until the fallout event was completed. It was not feasible to correct for space variation and vertical motions during this period because of lack of time and data.

Fallout plots

The fallout forecasts determined at the weapons-test operation were based entirely on measured data and quantitatively considered time variation of the wind. No space variation corrections or computed values of vertical motions were employed in their construction.

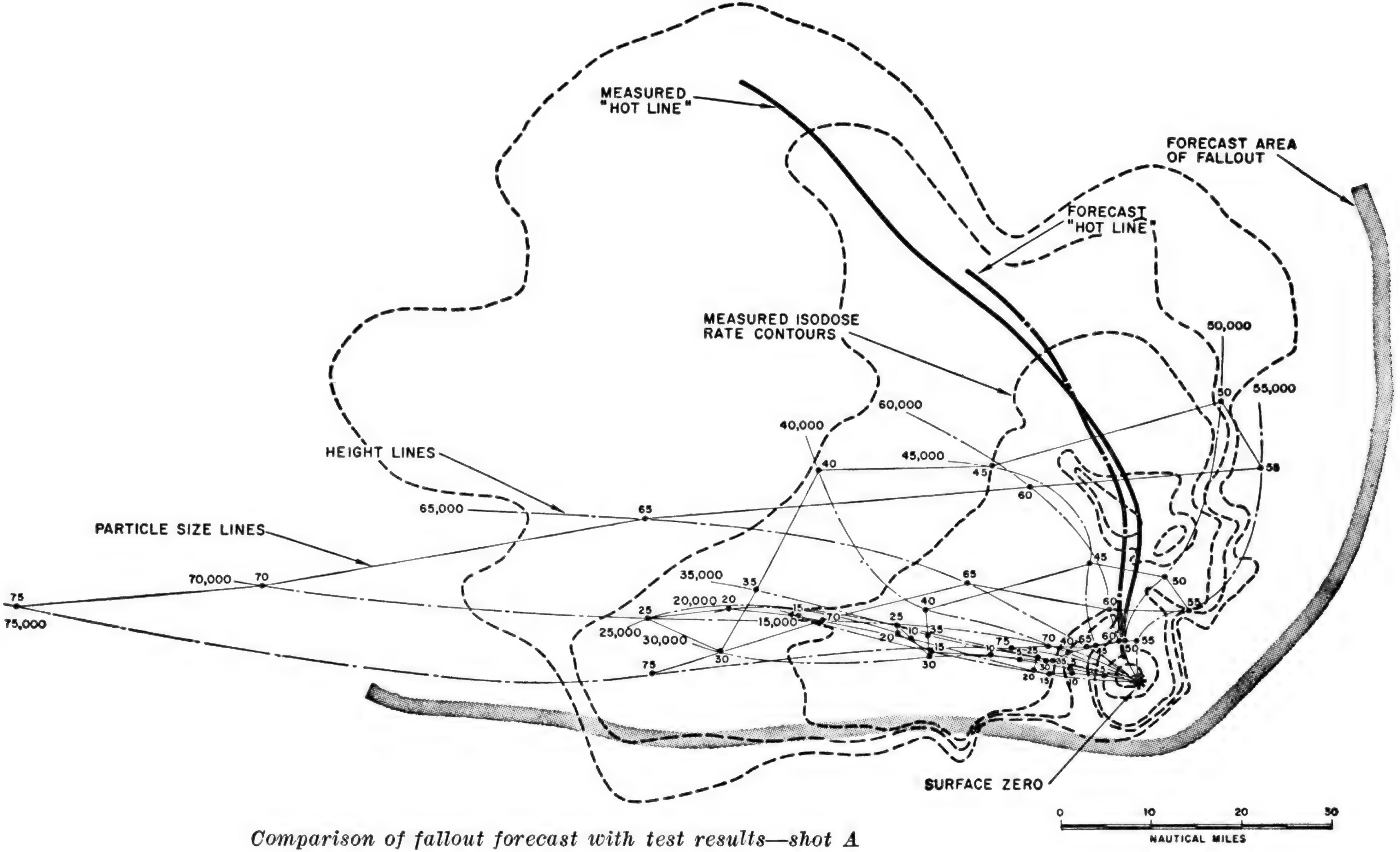
A and B were land-surface detonations, C and D were water-surface shots.

The comparison is excellent for all shots except B.

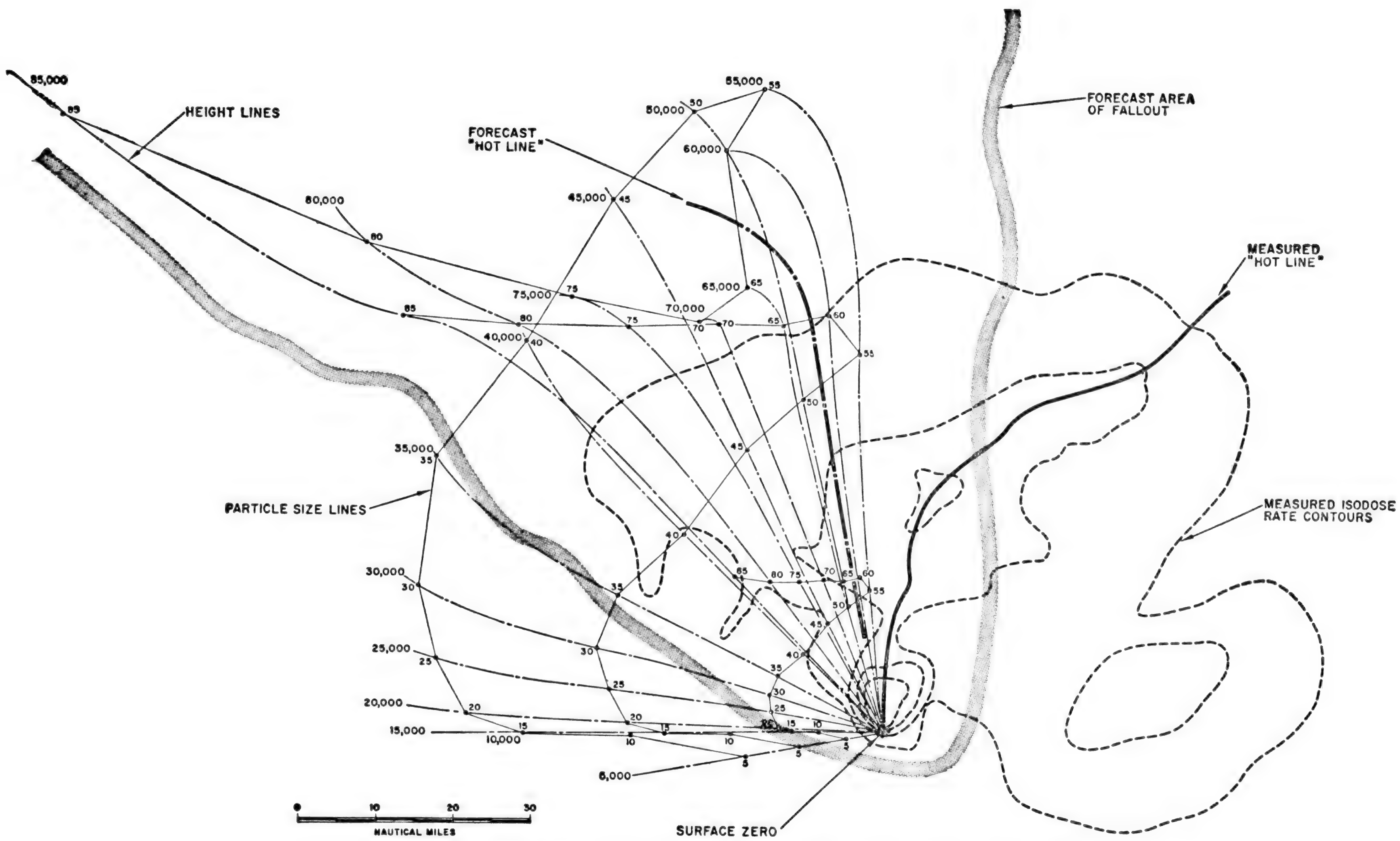
SUMMARY

The fallout forecasting technique described in this report was successfully employed for both land surface and water surface detonations at the Eniwetok Proving Ground. With known meterological data such a technique will successfully qualify the area of fallout and indicate qualitatively the relative intensity of radiation.

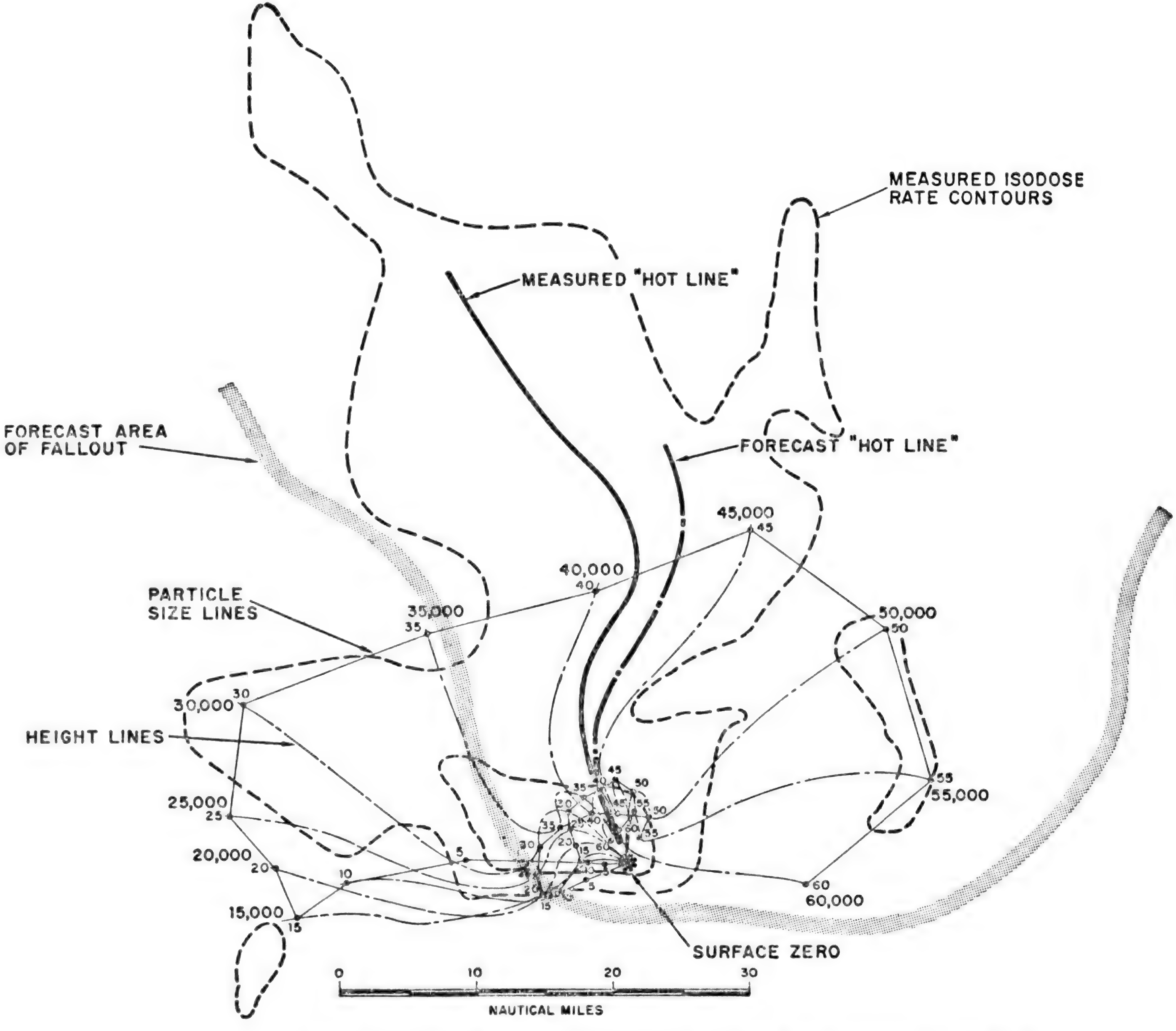
"Height lines" are deposit locations for all particles falling from a fixed altitude within the mushroom cloud. "Size lines" are deposit locations of a fixed particle size from various altitudes. A height line from the base of the mushroom disc is the "hot line".



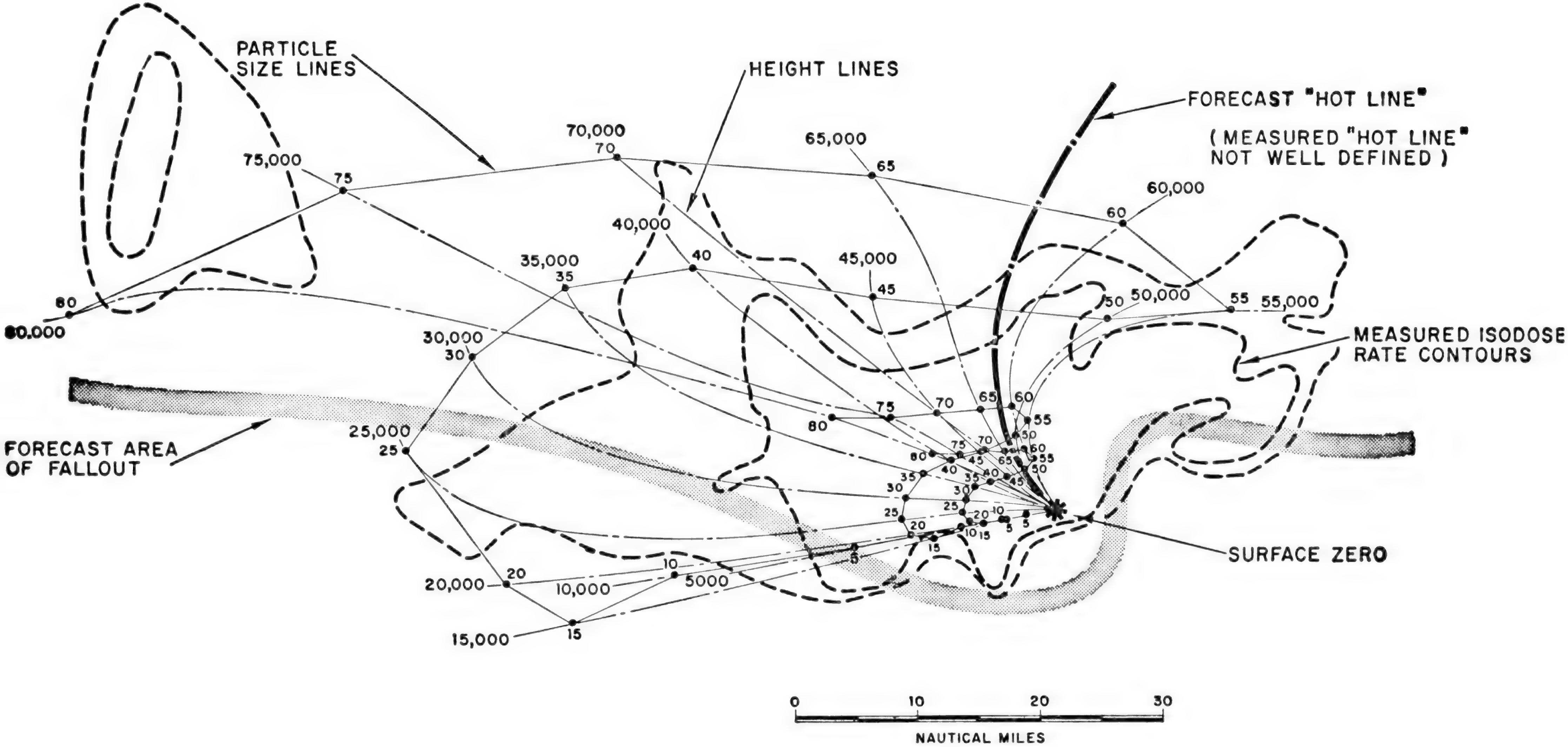
Comparison of fallout forecast with test results—shot A



Comparison of fallout forecast with test results—shot B.



Comparison of fallout forecast with test results—shot C.



Comparison of fallout forecast with test results—shot D.

WT-915

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OPERATION CASTLE

Project 2.5a

DISTRIBUTION AND INTENSITY OF FALLOUT

REPORT TO THE SCIENTIFIC DIRECTOR

by

R. L. Steton
E. A. Schuert
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H. K. Chan

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From SECRET
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Date 14 July 82
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January 1956

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U. S. Naval Radiological Defense Laboratory
San Francisco 24, California

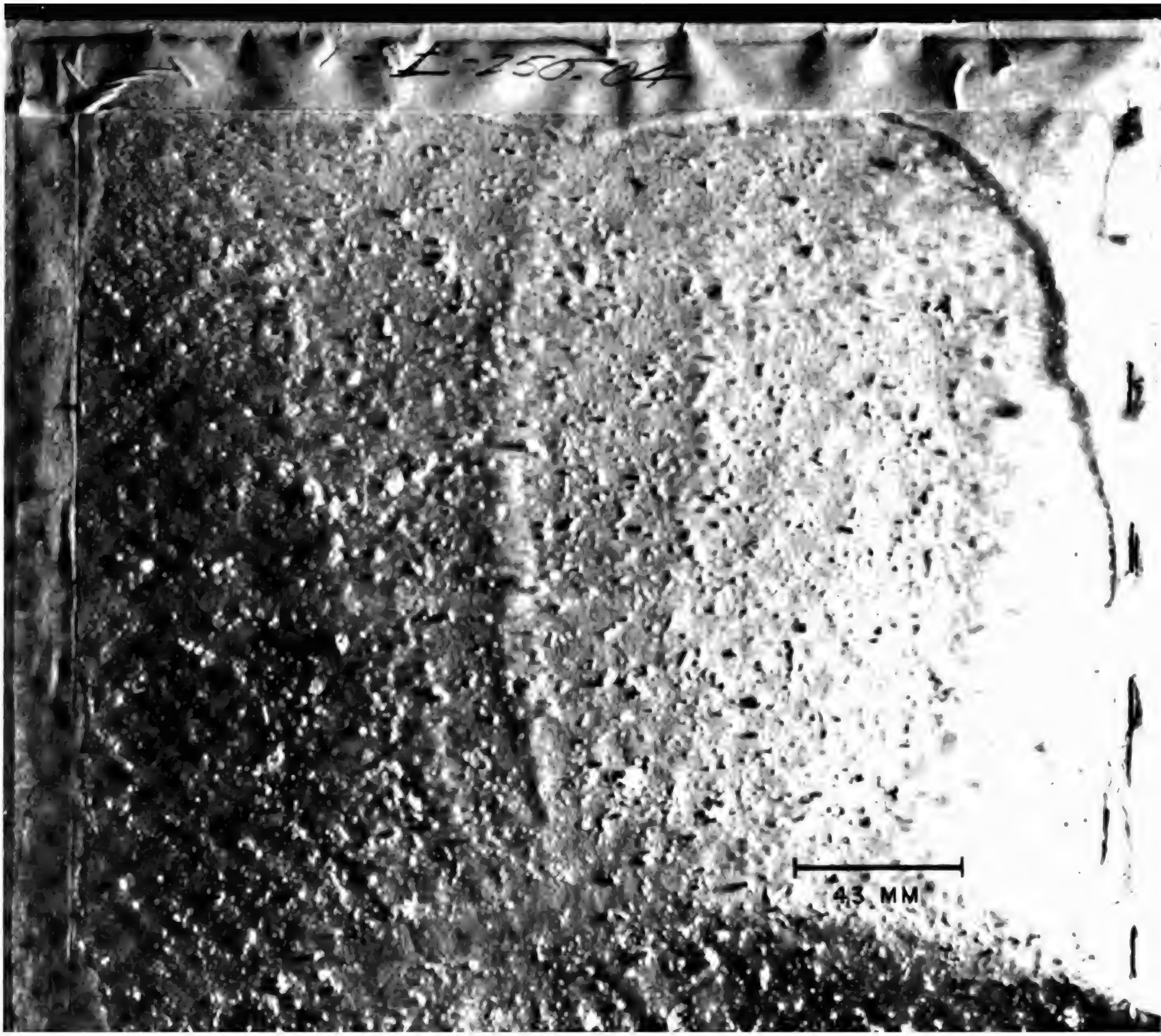

Fig. 5.10 Shot 1, Fallout Particulate, Station 250.04

This is a raft downwind in Bikini Lagoon, which received a land equivalent of 113 R/hr (1 hour reference gamma dose rate), according to Figures 2.2 and 6.1. Land equivalent dose rates were 7 times the raft dose rate in the lagoon.

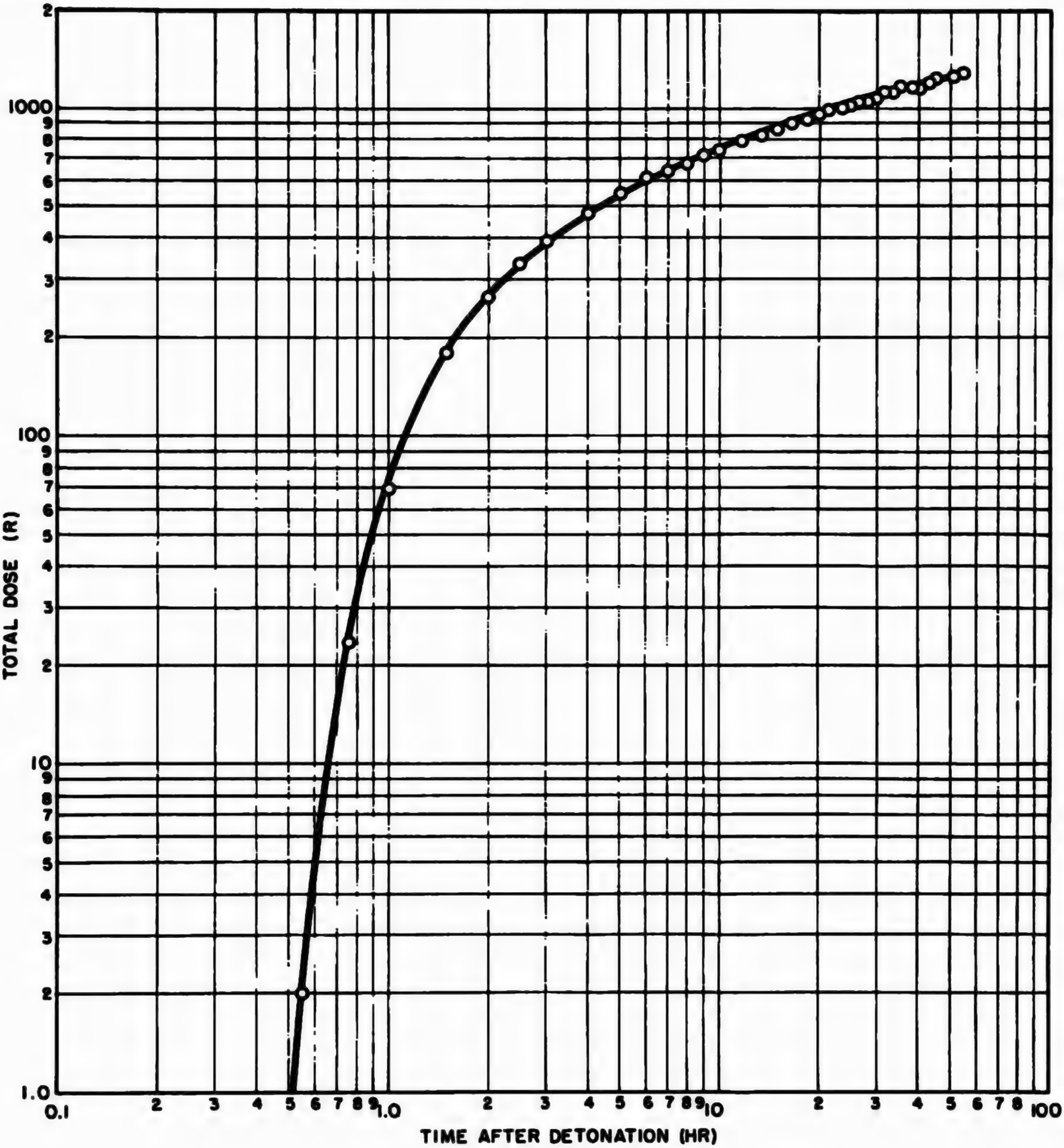

Fig. 5.11 Shot 1, Integrated Gamma Dose, Station 251.03

Bikini (How) Island in Bikini Atoll, which received a land equivalent of about 725 R/hr gamma at 1 hour reference time, according to Figures 2.2 and 6.1.

[redacted]

SANITIZED VERSION

TECHNICAL ANALYSIS REPORT - AFSWP NO. 507-SAN

RADIOACTIVE FALL-OUT HAZARDS FROM SURFACE BURSTS OF VERY HIGH YIELD NUCLEAR WEAPONS, Sanitized Version

by

D. C. Borg
L. D. Gates
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R. W. Paine, Jr.

WEAPONS EFFECTS DIVISION

This Armed Forces Special Weapons Project Technical Analysis Report is a staff study prepared for the Chief, AFSWP on a subject of military interest. The conclusions may be modified as new data become available.

MAY 1954

HEADQUARTERS, ARMED FORCES SPECIAL WEAPONS PROJECT
WASHINGTON 13, D. C.

[redacted]

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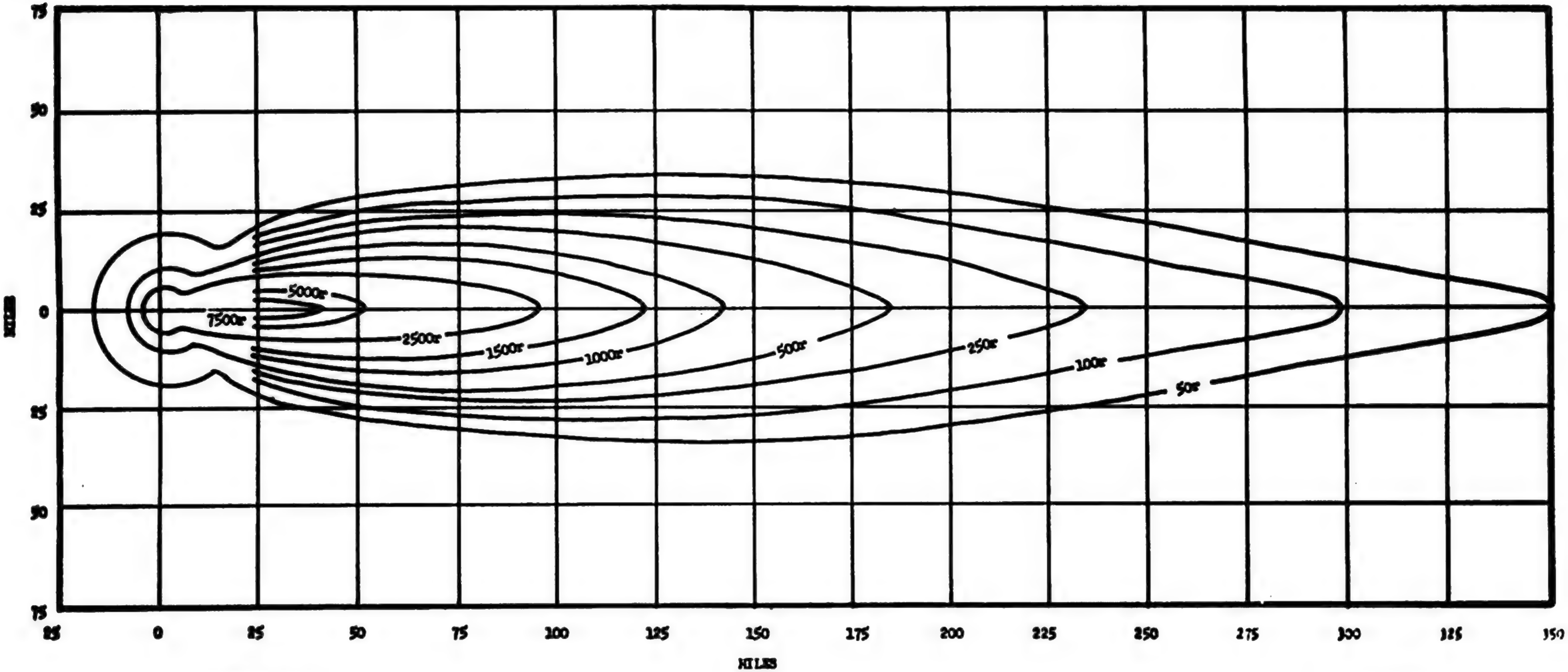
Fig. A TOTAL DOSE FRUH TIME OF FALL OUT TO H+50

Idealized Fall-out Contours for a 15 MT Land-surface Burst with a 15 Knot Effective Wind



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The shielding afforded by an ordinary frame house may effectively reduce the size of the hazard areas by a factor of about two, and a basement shelter by a factor of ten or more. Virtually complete protection against the lethal effects of radioactive fall-out can be obtained if personnel have protection equal to or better than that afforded by a simple underground shelter with at least three feet of earth cover, and if they are evacuated after a week or ten days in such a shelter.

One may draw the following conclusions from this analysis:

a. Very large areas, of the order of 5,000 square miles or more, are likely to be contaminated by the detonation of a 15 megaton yield weapon on land surface, in such intensities as to be hazardous to human life.

b. The fact that a large percentage of the radiologically hazardous area will lie outside the range of destructive bomb effects for normal wind conditions, extending up to several hundred miles downwind, makes the radiological fall-out hazard a primary anti-personnel effect.

c. Accurate pre-shot prediction of the location of the hazardous area with respect to the burst point is virtually impossible without extensive wind data at altitudes up to about 100,000 feet, owing to the sensitive wind-dependence of the distribution mechanism.

d. The fall-out contaminant can be expected to decay at such a rate that all but the most highly contaminated areas could be occupied by previously unexposed personnel on a calculated risk basis within a few days after the contaminating event; and even these highly contaminated areas may then be entered briefly by decontamination teams.

e. Passive defense measures, intelligently applied, can drastically reduce the lethally hazardous areas. A course of action involving the seeking of optimum shelter, followed by evacuation of the contaminated area after a week or ten days, appears to offer the best chance of survival. At the distant downwind areas, as much as 5 to 10 hours after detonation time may be available to take shelter before fall-out commences.

f. Universal use of a simply constructed deep underground shelter, a subway tunnel, or the sub-basement of a large building could eliminate the lethal hazard due to external radiation from fall-out completely, if followed by evacuation from the area when ambient radiation intensities have decayed to levels which will permit this to be done safely.

g. It is of vital importance for individuals in hazardous areas to seek optimum shelter at once, since the dosage received in the first few hours after fall-out has commenced will exceed that received over the rest of a week spent in the contaminated area.

Table II

Total Isodose Contour: 500r from Fall-out to H+50 Hours

Yield (MT)	15	1	10	60	* 60
Downwind extent (mi)	180	52	152	340	(307)
Crosswind axis (mi)	40	12	34	70	
GZ circle radius (mi)	11.5	3.85	9.7	21	
GZ circle displacement (mi)	3.5	1.2	3	5.75	
Area (mi^2)	5400	470	3880	17,900	(16,250)
Area of true ellipse (mi^2)	(5650)	(491)	(4055)	(18,700)	

* Using Part D, Chapter II.

Table VII

Minimum Dosages Within Areas
For City Decontamination
15 MT Surface Burst

Case When Decontamination Takes 2.2 Days and Starts at H+2 Days

AREA	1000 mi²	3000 mi²	5000 mi²	8000 mi²
Damage dose after staying in best average shelter (fall-out time to H+2 days)	160 r	65 r	40 r	23 r
Damage dose during decontamination effort received by 66% of population which is engaged (H+2 days to H+4.2 days)	120 r	50 r	30 r	17 r
Total Damage dose received up to H+4.2 days	280 r	115 r	70 r	40 r
Acute biological effect	LD/1 SD/55	None	None	None

Case When Decontamination Takes 13 Days and Starts at H+6 Days

AREA	1000 mi²	3000 mi²	5000 mi²	8000 mi²
Damage dose before decontamination begins when in best average shelter (fall-out time to H+6 days)	240 r	110 r	60 r	30 r
Damage dose during decontamination effort received by 60% of population which is engaged (H+6 Days to H+19 days)	(No additional damage dose received due to biological recovery)			
Total damage dose received up to H+19 days	240 r	110 r	60 r	30 r
Acute biological effect	SD/25	None	None	None

Proceedings of the Symposium
held at Washington, D. C.
April 19-23, 1965 by the
Subcommittee on Protective Structures,
Advisory Committee on Civil Defense,
National Academy of Sciences—
National Research Council

Protective Structures

for

CIVILIAN POPULATIONS

1966

MODEL ANALYSIS

Mr. Ivor Ll. DAVIES
Suffield Experimental Station
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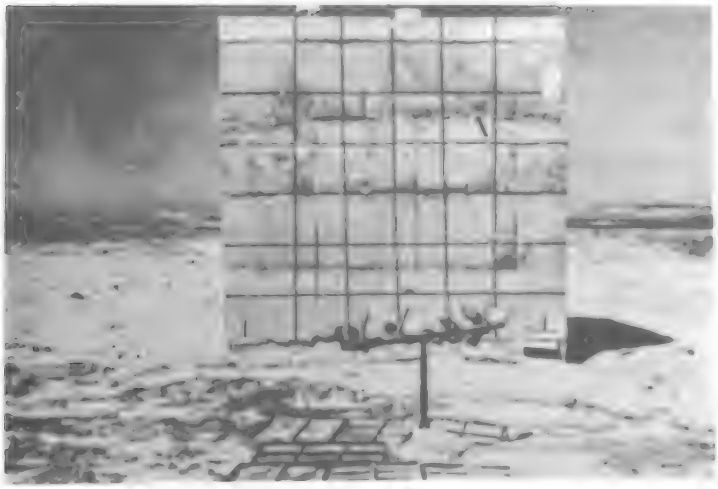
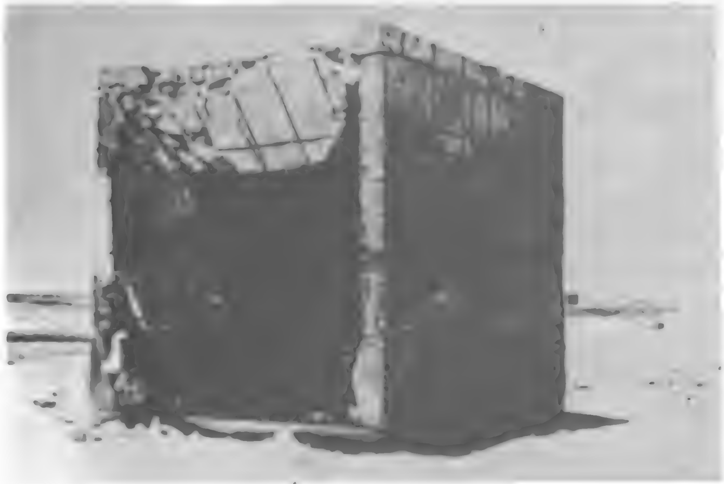
Nuclear-Weapon Tests

In 1952 we fired our first nuclear device, effectively a "nominal" weapon, at Monte Bello, off northwest Australia. To the blast loading from this weapon we exposed a number of reinforced-concrete cubicle structures that had been designed for the dynamic loading conditions, and for which we made the best analysis of response we were competent to make at that time. Our estimates of effects were really a dismal failure. The structures were placed at pressure levels of 30, 10, and 6 psi, where we expected them to be destroyed, heavily damaged with some petaling of the front face, and extensively cracked, respectively. In fact, the front face of the cubicle at 30 psi was broken inwards; failure had occurred along both diagonals, and the four triangular petals had been pushed in. At the 10-psi level, where we had three cubicles, each with a different wall thickness (6, 9, and 12 in.), we observed only light cracking in the front face of that cubicle with the least thick wall (6 in.). The other two structures were apparently undamaged, as was the single structure at the 6-psi level.



10 p.s.i.



34 p.s.i.

Dynamic tests, Monte Bello cubicles.

In 1957, the first proposals were made for the construction of the underground car park in Hyde Park in London. The Home Office was interested in this project since, in an emergency, the structure could be used as a shelter. Consequently a request was made to us at Atomic Weapons Research Establishment (A.W.R.E.) to design a structure that would be resistant to a blast loading of about 50 psi, and to test our design on the model scale.

Using the various load-deformation curves obtained in this test, an estimate was made of the response of the structure to blast loading. Of particular interest was the possible effect of 100 tons of TNT, the first 100-ton trial at Suffield in Alberta.

A total of seven more models was made; six were shipped to Canada and placed with the top surface of the roof flush with the ground and at positions where peak pressures of 100, 80, 70, 60, 50, and 40 psi were expected. The seventh model was kept in England for static testing at about the time of firing. The results were not as expected. In the field, the four models farthest from the charge were apparantly undamaged; we could see no cracking with the eye, nor did soaking the models with water reveal more than a few hair cracks. The model nearest the charge was lightly cracked in the roof panels and beams, and one of the columns showed slight spalling at the head. This model had been exposed to a peak pressure of 110 psi.

BLAST AND OTHER THREATS

Harold Brode
The RAND Corporation, Santa Monica, California

Chemical High-Explosive Weapons

As in past aerial warfare, bombs and missiles carrying chemical explosives to targets are capable of extensive damage only when delivered in large numbers and with high accuracy.

Biological Warfare

Most biological agents are inexpensive to produce; their effective dissemination over hostile territories remains the chief deterrent to their effective employment. Twenty square miles is about the area that can be effectively covered by a single aircraft; large area coverage presents a task for vast fleets of fairly vulnerable planes flying tight patterns at modest or low altitudes. While agents vary in virulence and in their biologic decay rate, most are quite perishable in normal open-air environments. Since shelter and simple prophylactic measures can be quite effective against biological agents, there is less likelihood of the use of biological warfare on a wholesale basis against a nation, and more chance of limited employment on population concentrations —perhaps by covert delivery, since shelters with adequate filtering could insure rather complete protection to those inside.

Chemical Weapons

Chemical weapons, like biological weapons, are relatively inexpensive to create, but face nearly insurmountable logistics problems on delivery. Although chemical agents produce casualties more rapidly, the greater amounts of material to deliver seriously limit the likelihood of their large-scale deployment. Furthermore, chemical research does not hold promise of the development of significantly more toxic chemicals for future use.

Radiological Weapons

The advantages of such modifications are much less real than apparent. In all weapons delivered by missiles, minimizing the payload and total weight is very important. If the total payload is not to be increased, then the inclusion of inert material to be activated by neutrons must lead to reductions in the explosive yield. If all the weight is devoted to nuclear explosives, then more fission-fragment activity can be created, and it is the net difference in activity that must be balanced against the loss of explosive yield. As it turns out, a fission explosion is a most efficient generator of activity, and greater total doses are not achieved by injecting special inert materials to be activated.

Perret, W.R., Ground Motion Studies at High Incident Overpressure, The Sandia Corporation, Operation PLUMBBOB, WT-1405, for Defense Atomic Support Agency Field Command, June 1960.

The Neutron Bomb

The neutron bomb, so called because of the deliberate effort to maximize the effectiveness of the neutrons, would necessarily be limited to rather small yields—yields at which the neutron absorption in air does not reduce the doses to a point at which blast and thermal effects are dominant. The use of small yields against large-area targets again runs into the delivery problems faced by chemical agents and explosives, and larger yields in fewer packages pose a less stringent problem for delivery systems in most applications. In the unlikely event that an enemy desired to minimize blast and thermal damage and to create little local fallout but still kill the populace, it would be necessary to use large numbers of carefully placed neutron-producing weapons burst high enough to avoid blast damage on the ground, but low enough to get the neutrons down. In this case, however, adequate radiation shielding for the people would leave the city unscathed and demonstrate the attack to be futile.

The thermal radiation from a surface burst is expected to be less than half of that from an air burst, both because the radiating fireball surface is truncated and because the hot interior is partially quenched by the megatons of injected crater material.

SUPERSEISMIC GROUND-SHOCK MAXIMA (AT 5-FT DEPTH)

Vertical acceleration: $\alpha_{vm} \simeq 340\,\Delta P_s/C_L$ ± 30 per cent. Here acceleration is measured in g's and overpressure (ΔP_s) in pounds per square inch. An empirical refinement requires C_L to be defined as the seismic velocity (in feet per second) for rock, but as three fourths of the seismic velocity for soil.

OUTRUNNING GROUND-SHOCK MAXIMA (AT ~10-FT DEPTH)

Vertical acceleration: $\alpha_{vm} \simeq 2 \times 10^5/C_L r^2$ + factor 4 or -factor 2. Acceleration is measured in g's, and r is the scaled radial distance—i.e., $r = R/W^{1/3}$ kft/(mt)$^{1/3}$.

Data taken on a low air-burst shot in Nevada indicate an exponential decay of maximum displacement with depth. For the particular case of a burst of ~ 40 kt at 700 ft, some measurements were made as deep as 200 ft below the surface of Frenchman Flat, a dry lake bed, which led to the following approximate decay law, according to Perret.

$$\delta = \delta_0 \exp(-0.017D),$$

where δ represents the maximum vertical displacement induced at depth D, δ_0 is the maximum displacement at the surface, and D is the depth in feet.

THE PROTECTION AGAINST FALLOUT RADIATION AFFORDED BY CORE SHELTERS IN A TYPICAL BRITISH HOUSE

Daniel T. Jones
Scientific Adviser, Home Office, London

Protective Factors in a Sample of British Houses (Windows Blocked)

Protective Factor	Percentage of Houses
< 25	36%
25-39	28%
40-100	29%
> 100	7%

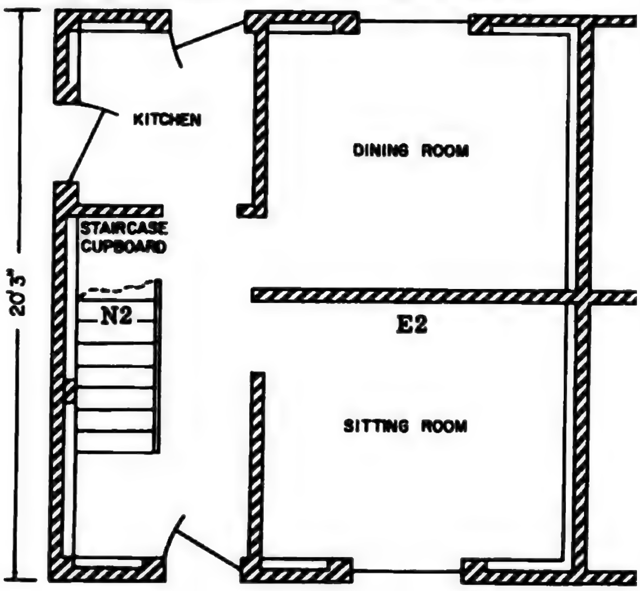
"A very much improved protection could be obtained by constructing a shelter core. This means a small, thick-walled shelter built preferably inside the fallout room itself, in which to spend the first critical hours when the radiation from fallout would be most dangerous."(1)

The full-scale experiments were carried out at the Civil Defense School at Falfield Park.(2)

In the staircase construction, the shelter consisted of the cupboard under the stairs, sandbags being placed on treads above and at the sides.

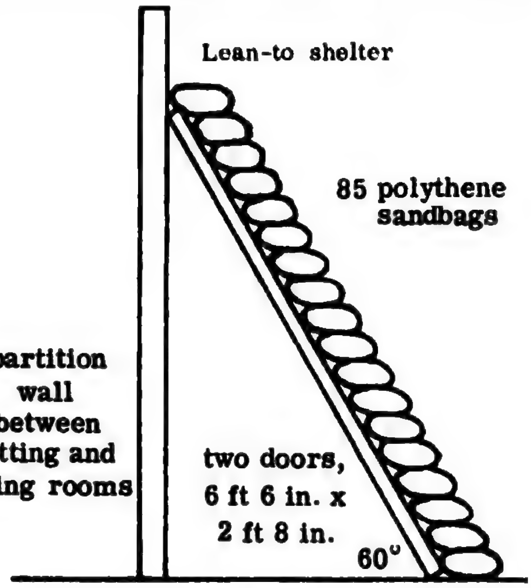
A 93 curies cobalt-60 source was used.

1. Six sandbags per tread, and a double layer on the small top landing. 96 sandbags were used.
2. As (1), together with a 4-ft-high wall of sandbags along the external north wall. 160 sandbags were used.
3. As (2), together with 4-ft-high walls of sandbags along the kitchen/cupboard partition wall and along the passage partition. 220 sandbags were used.



9 in. brick walls The windows and doors were not blocked	Position	contribution r/hr/c/ft² Ground	Roof	Protective Factor
House only	E2	15.0	8.4	21
Lean-to	E2	10.4	2.4	39
Staircase cupboard:				
Stairs only sandbagged	N2	29.2	5.3	14
Stairs and outer wall sandbagged	N2	16.4	4.6	24
Stairs, outer wall, kitchen wall and corridor partition sandbagged	N2	8.8	1.8	47

sandbags 24 in. x 12 in. when empty; 16 in. x 9 in. x 4 in. when filled with 25 lb of sand.



floor area 21 sq ft.

1. Civil Defence Handbook No. 10, HMSO, 1963.
2. Perryman, A. D., Home Office Report CD/SA 117.

Foreword

If the country were ever faced with an immediate threat of nuclear war, a copy of this booklet would be distributed to every household as part of a public information campaign which would include announcements on television and radio and in the press. The booklet has been designed for free and general distribution in that event. It is being placed on sale now for those who wish to know what they would be advised to do at such a time.

May 1980

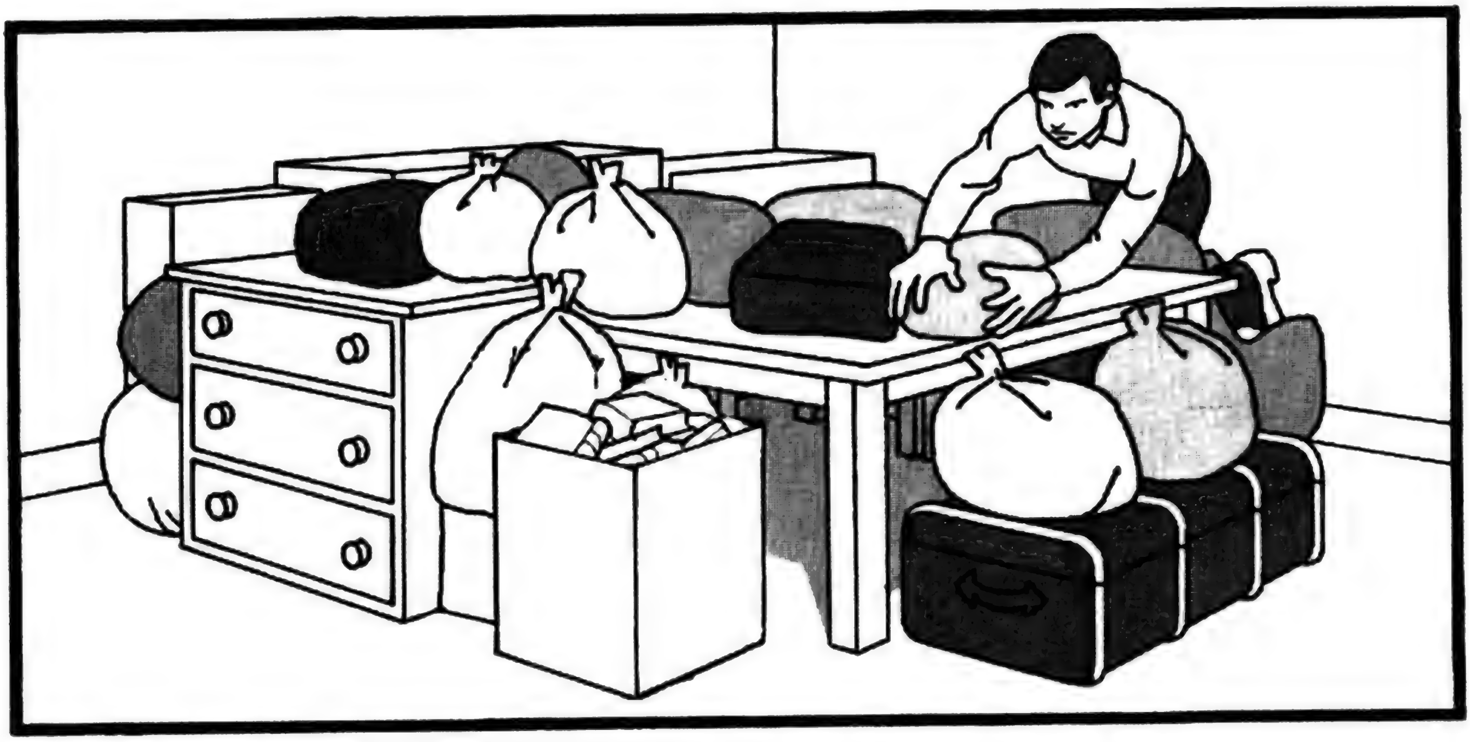
Protect and Survive
ISBN 0 11 3407289

If Britain is attacked by nuclear bombs or by missiles, we do not know what targets will be chosen or how severe the assault will be.

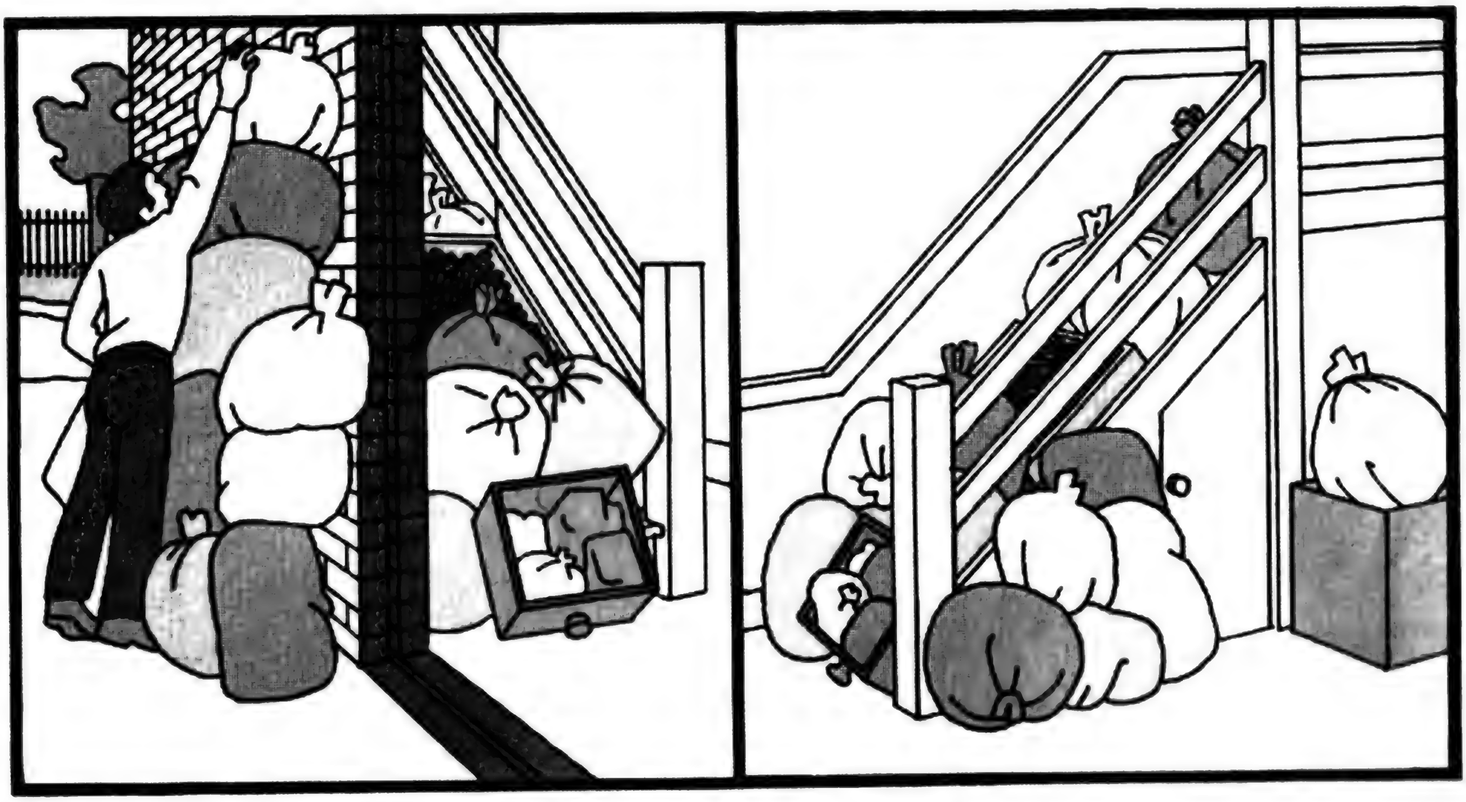
If nuclear weapons are used on a large scale, those of us living in the country areas might be exposed to as great a risk as those in the towns. The radioactive dust, falling where the wind blows it, will bring the most widespread dangers of all. No part of the United Kingdom can be considered safe from both the direct effects of the weapons and the resultant fall-out.

The dangers which you and your family will face in this situation can be reduced if you do as this booklet describes.

Use tables if they are large enough to provide you all with shelter. Surround them and cover them with heavy furniture filled with sand, earth, books or clothing.



Use the cupboard under the stairs if it is in your fall-out room. Put bags of earth or sand on the stairs and along the wall of the cupboard. If the stairs are on an outside wall, strengthen the wall outside in the same way to a height of six feet.



What to do after the Attack:

After a nuclear attack, there will be a short period before fall-out starts to descend. Use this time to do essential tasks. This is what you should do.

Do not smoke.

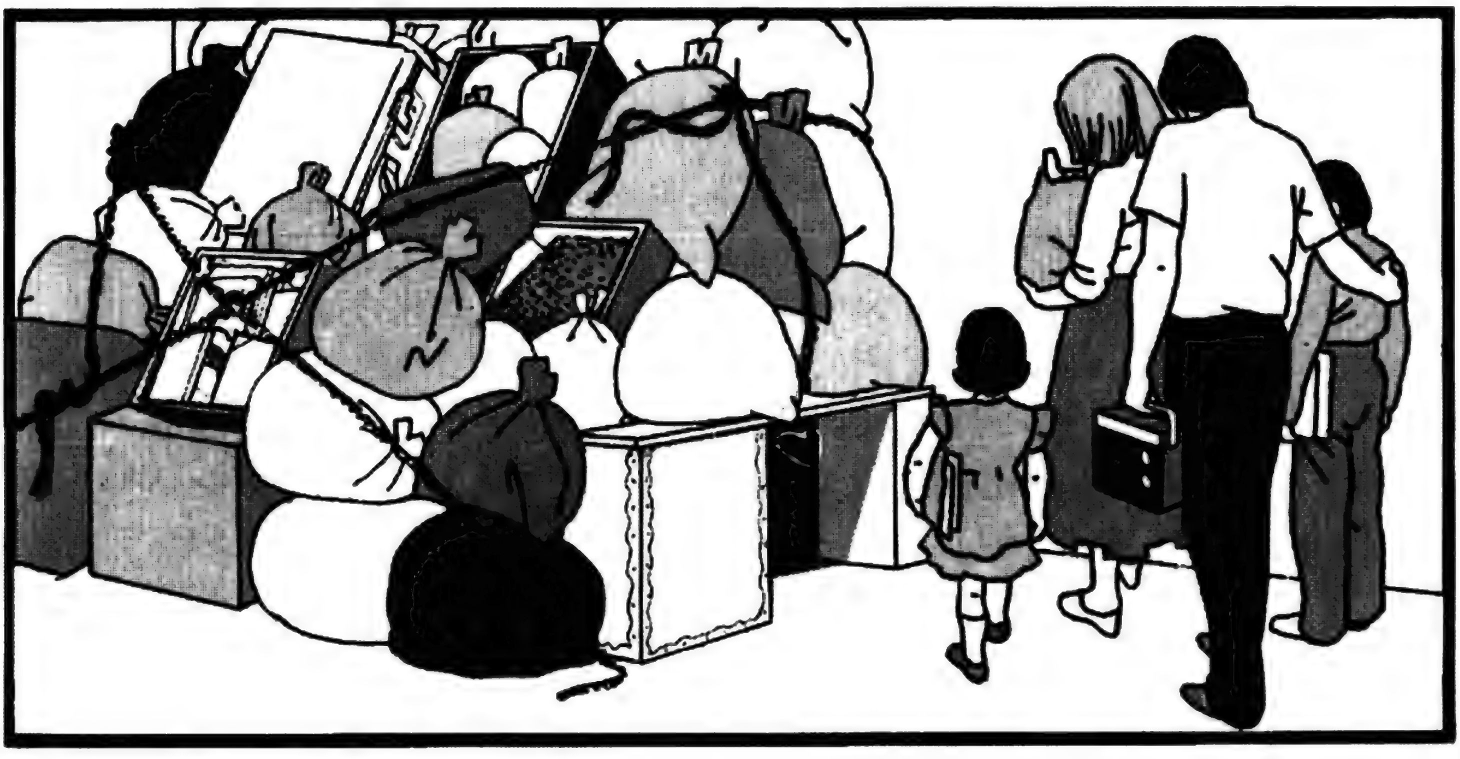
Check that gas, electricity and other fuel supplies and all pilot lights *are* turned off.

Go round the house and put out any small fires using mains water if you can.

If anyone's clothing catches fire, lay them on the floor and roll them in a blanket, rug or thick coat.

If there is structural damage from the attack you may have some time before a fall-out warning to do minor jobs to keep out the weather – using curtains or sheets to cover broken windows or holes.

If you are out of doors, take the nearest and best available cover as quickly as possible, wiping all the dust you can from your skin and clothing at the entrance to the building in which you shelter.



SEPTEMBER 1964

HOME OFFICE

CD/SA 121

SCIENTIFIC ADVISER'S BRANCH

IGNITION AND FIRE SPREAD IN URBAN AREAS FOLLOWING A NUCLEAR ATTACK

G. R. Stanbury

INITIAL FIRE INCIDENCE

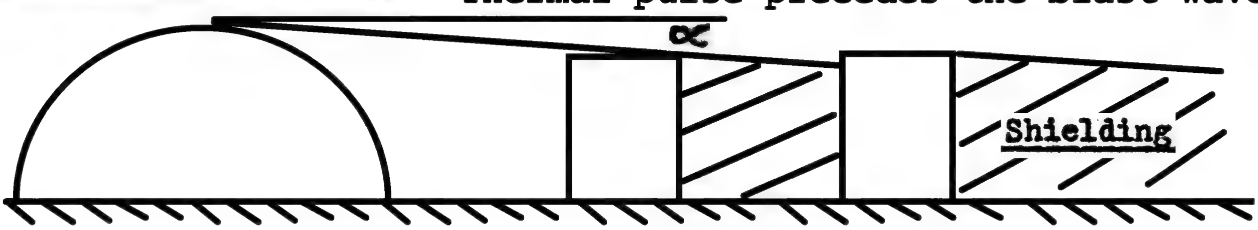
For a 1 MT groundburst bomb the height of the top of the fireball above ground is about 0.72 miles. Because this distance is large compared with the height of most buildings, the exposed upper floors do actually see a large part of the fireball and not just the top of it, but in assuming that the radiation is just as intense from the top as from the middle we were overestimating the fire risk.

On the above basis the following table gives the number of exposed upper floors (to the nearest ½ floor) for a range of distances from the explosion and a range of street widths.

Effect of Shielding: Estimation of the number of exposed floors

Assuming that buildings on opposite sides of a street which is receiving heat radiation from a direction perpendicular to its length are of the same height

Thermal pulse precedes the blast wave



Distance from explosion miles	Angle of arrival α^{o}	tan α	Width of street (units of 10 ft.)						
			2	3	4	5	6	7	8
1	35	.72	1.5	2	3	3.5	4.5	5	6
1½	26	.48	1	1.5	2	2.5	3	3.5	4
2	20	.36	.5	1	1.5	2	2	2.5	3
3	13½	.24	.5	.5	1	1	1.5	1.5	2
4	10	.18	.5	.5	.5	1	1	1.5	1.5
5	8	.15	.5	.5	.5	.5	1	1	1

we take the average depth of a floor to be 10 ft.

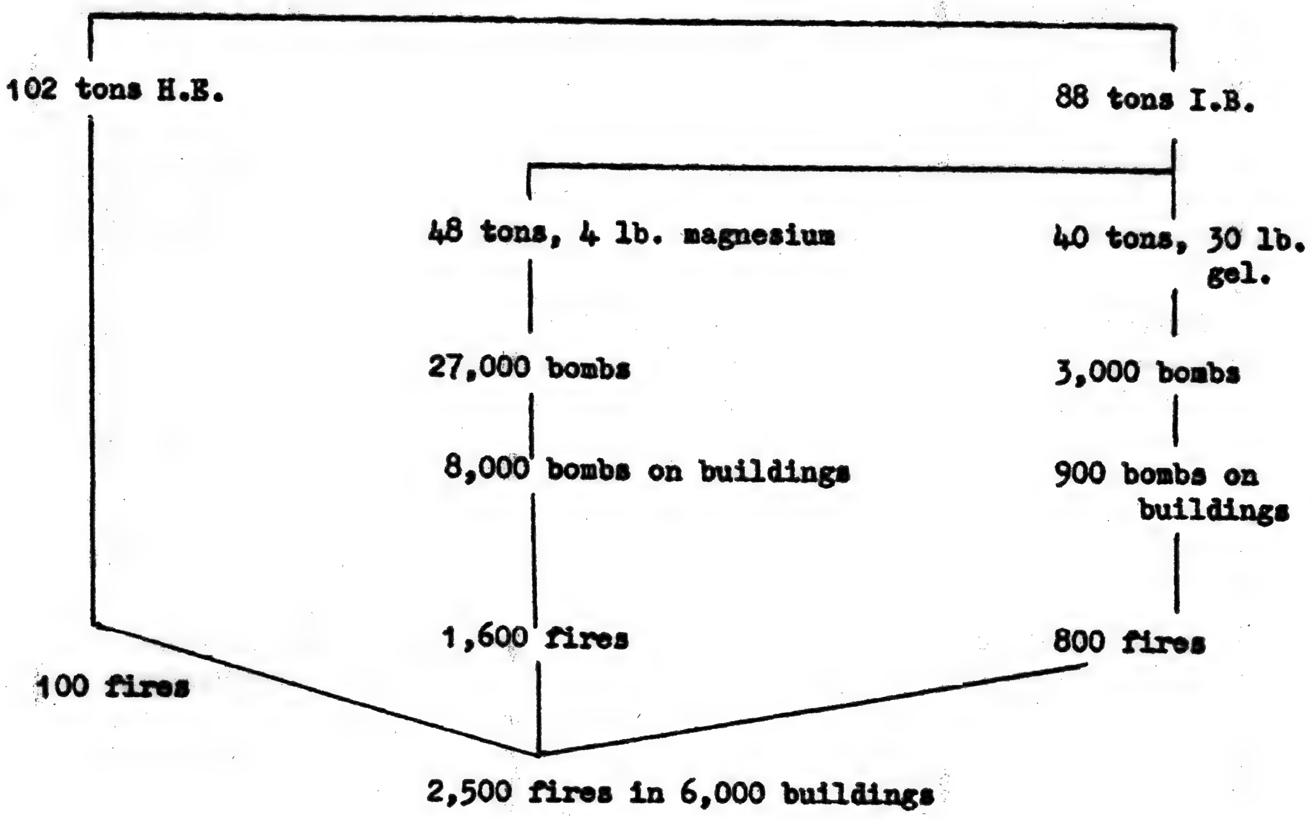
Angle between heat flash and street (degrees)	90-75	75-60	60-45	45-30	30-15	15-0
Proportion of heat flash entering windows %	99	92.5	80	60	40	14

SPREAD OF FIRE

From last war experience of mass fire raids in Germany it was concluded that the overall spread factor was about 2; i.e. about twice as many buildings were destroyed by fire as were actually set alight by incendiary bombs

Number of fires started per square mile in the fire-storm raid on Hamburg, 27th/28th July, 1943

Bombs dropped



However, the important thing to note is that the total number of fires started in each square mile (2,500) was nearly half that of the total number of buildings; in other words, almost every other building was set on fire during the raid itself. When this happened no fire-fighting organisation, however efficient could hope to prevent the fires from joining together and engulfing the whole area.

When the figure of 1 in 2 for the German fire storms is compared with the figures for initial fire incidence of $\sim$ 1 in 15 to 30 obtained in the Birmingham and Liverpool studies it can only be concluded that a nuclear explosion could not possibly produce a fire storm.

Fire situation from 1,499 fly bombs in the built-up part of the London Region

WWII V1 high explosives (1 ton TNT warhead) (cruise missiles)

Where dropped	Number of fly bombs	Fly Bombs Caused				
		No fire	Small fire	Medium fire	Serious fire	Major fire
City	119 ~~199~~	47	49	17	4	2
West-End	33	8	22	2	-	1
Closed Residential	430	207	203	20	-	-
Open Residential	804	478	296	28	2	-
Docks	113	64	39	8	1	1
Grand Totals	1,499	804	609	75	7	4

Discussion of results

Two important points emerge from a study of these results:-

(i) The small proportion of fly bombs - less than 20% - which started fires of any greater category than "small" even in the most heavily built-up areas; and

(ii) The large proportion which started no fires at all even in the most heavily built-up areas.

All these fly bombs fell in the summer months of 1944 which were unusually dry. In winter in this country in residential areas there are many open fires which may provide extra sources of ignition. The domestic occupancy is a low fire risk however, and as the proportion of such property in the important City and West End areas is small this should not introduce any serious error. Moreover, in winter, the high atmospheric humidity and the correspondingly high moisture content of timber would tend to retard or even prevent the growth of fire.

In order to determine how many fly bombs are equivalent to one nominal atomic bomb one method is to compare the areas over which a given category of house damage is produced by each. If we do this for a $\frac{3}{8}$th mile air burst as at Hiroshima, the result is that 1 atomic bomb does as much damage as about 1,200 fly bombs.

This in itself is not a serious fire situation and it is doubtful whether it could ever give rise to a fire storm. In Hamburg 2,500 fires were started per square mile by a bomb density (combined H.E. and I.B.) of 2oo tons per square mile, and for the area of destruction produced by an atomic bomb this would correspond to a total of about 10,000 fires.

DOMESTIC NUCLEAR SHELTERS

TECHNICAL GUIDANCE

A HOME OFFICE GUIDE

Introduction

This manual of technical guidance on the design of domestic nuclear shelters has been prepared by a working group set up by the Emergency Services Division of the Home Office. The working group was asked to consider designs of nuclear shelters which could be made available to members of the public in the United Kingdom who might wish to purchase and install shelters for the use of themselves and their families.

The working group realised that the range of designs which it might produce would not be exhaustive. However, it was aware of the need to give technical guidance to professional engineers to assist them in producing reliable shelter designs. Thus the first three chapters of this book are written to give such guidance.

The other four chapters of the book give detailed designs of five shelters. These five cover a range of types which are applicable to different sorts of houses; they also cover a wide price range. These designs are not intended to be exhaustive, and as explained in the text, the working group is already giving attention to other designs, particularly those which might be incorporated into existing or new houses and also underground shelters of shapes other than box-like and using materials other than concrete. It is planned to publish details of this work at a later date.

The members of the working group are:

Mr J C Cotterill, *Chairman*	Scientific Advisory Branch, Home Office
Dr J R Stealey	Scientific Advisory Branch, Home Office
Mr A Lindfield	Scientific Advisory Branch, Home Office
Mr K A Day	F6 Division, Home Office
Mr R W T Haines, C Eng	Directorate of Works, Home Office
Mr H G S Banks, C Eng	Directorate of Works, Home Office
Mr M Connell, C Eng	Directorate of Civil Engineering Services Property Services Agency, Department of Environment
Mr S Bell, C Eng	Directorate of Civil Engineering Services Property Services Agency, Department of Environment
Mr S England, C Eng	Directorate of Mechanical and Electrical Engineering Services Property Services Agency, Department of Environment
Mr I Leys	Atomic Weapons Research Establishment, Ministry of Defence Foulness
Major I C T Ingall	HQ United Kingdom Land Forces Wilton, Wilts.
Mr R Million, *Secretary*	F6 Division, Home Office

Any enquiries concerning this manual should be addressed to the Home Office, F6 Division, and not to individual members of the working group.

To obtain some protection from the heat it is necessary to move out of the direct path of the rays from the fireball; any kind of shade will be of some value. In shelter design, any materials affording protection against ionising radiation or blast will give more than adequate protection against the heat. However it is important to ensure that no exposed parts of the shelter (such as the facings of doors) are made of flammable materials. In the case of shelters made from plastic materials such as GRP (glass reinforced plastic) it is essential that no surfaces should be exposed to the heat pulse. It is unlikely that such plastic materials would catch fire, but they may melt or distort. Since the blast wave follows the heat pulse, such distorted areas may result in lowered blast resistance.

It is considered unlikely that the heat flash from a nuclear explosion would give rise to fire-storms. In the last war, fire-storms were caused in the old city of Hamburg as a result of heavy incendiary attacks and at Hiroshima but not at Nagasaki. A close study of these cities and of German cities where fire-storms did and did not occur revealed several interesting features. A fire-storm occurred only in an area of several square miles, heavily built up with buildings containing plenty of combustible material and where at least every other building in the area had been set alight. It is not considered that the initial density of fires, equivalent to one in every other building, would be caused by a nuclear explosion over a British city. Studies have shown that due to shielding, a much smaller proportion of buildings than this would be exposed to the heat flash. Moreover, the buildings in the centres of most British cities are now more fire-resistant and more widely spaced than they were 30 to 40 years ago. This low risk of fire-storms would be reduced still further by the control of small initial and secondary fires.

There are two main hazards from a large area of fire to the occupants of shelters. One is the transmission of heat through the earth and shelter wall. In most cases this would make for discomfort rather than danger, particularly in underground shelters. The major danger is the possibility that the gaseous products of combustion, mainly carbon dioxide and perhaps carbon monoxide, might be drawn into the shelter. These dangers may be mitigated by taking advantage of the fact that the arrival of fallout is unlikely to occur for about half an hour after the explosion and a fallout warning will be given (for details see the booklet *Protect and Survive*). The intervening time might be used to try to extinguish or damp down any nearby fires. This may not be possible in many cases where a fallout warning has already been given based on ground bursts further upwind than the local bomb.

Crater formation and ground shock

When a nuclear weapon bursts near the ground much of the energy is expended in making a crater. At the same time a shock wave is transmitted outwards through the ground.

Crater formation

A large amount of vapourised or pulverised material is sucked up by the ascending fireball. Larger amounts are gouged out and deposited on the perimeter of the crater making an elevated lip roughly equal in width to the radius of the crater itself. The size of the crater, for a weapon of given power, will depend on the nature of the ground and

Fig. 6 ***Approximate ranges of blast damage to UK houses (from 1 MT groundburst)***

Designation	Radial distance	Overpressure	Effect	Death/injury
A ring	Up to 2.5 km (1½ mi)	77 kPa plus. (11 psi)	Houses totally destroyed	High probability of death or serious injury
B ring	2.5 to 3.5 km (1½ to 2¼ mi)	77 to 42 kPa (11 to 6 psi)	Houses irreparably damaged	About 10% killed; 35% trapped; others injured
C ring	3.5 to 9 km (2¼ to 5½ mi)	42 to 10 kPa (6 to 1.5 psi)	Houses with moderate to severe damage	About 25% trapped or seriously injured at inner edge of ring
D ring	9 to 14 km (6 to 9 mi)	10 to 5 kPa (1.5 to 0.75 psi)	Houses lightly damaged	No deaths; few injuries expected

(WWII house damage vs injury data)

The debris problem

From Fig. 6 it can be deduced that the problems of debris around buried shelters might be serious in some locations near to ground zero. It is important that entrances or escape hatches and ventilation pipes where included should be as far as possible from nearby buildings — at least a distance equal to one-half the height (measured to the eaves) of the nearest building.

Trees are very vulnerable to long duration blast waves and in some areas these might cause obstruction to shelter entrances. The blast from a 1 MT groundburst would blow down 90 per cent of trees at a distance of 6 km (3¾ miles), 30 per cent at 7 km (4½ miles) and cause damage to branches out to 10 km (6¼ miles).

Initial nuclear radiation (INR)

Neutrons and gamma rays are emitted instantaneously by a nuclear explosion and these are followed by the gamma radiation from the intensely radioactive products in the fireball. This radiation is called initial nuclear radiation and is defined as that radiation emitted within one minute after detonation. In fact most of this hits the ground within a few seconds since the rapid rise of the fireball quickly takes the gamma rays and neutrons out of range. The phenomenon of initial nuclear radiation is very complex and not completely understood, but four facts are of importance for shelter design.

1. Range of INR

The intensity of INR falls off very rapidly with distance. The dose of INR received by a person in the open 2.5 km (1½ miles) from a 1 MT burst would give only a 50 per cent chance of survival. At 2.8 km (1¾ miles) the dose received would be negligible. At those distances, of course, anyone in the open would be killed by the blast. One important difference between kiloton and megaton weapons is the relationship between blast and INR ranges. With the smaller kiloton weapons the range of INR extends beyond the range of lethal blast; the reverse is true for megaton weapons. The Hiroshima and Nagasaki weapons were in the kiloton range and produced lethal INR effects. Fig. 7 gives the approximate exposures in roentgens of INR at locations where the blast overpressures are significant. Shelters designed to withstand a given overpressure should also be designed to protect against this level of INR. Overpressures are given in kiloPascals (psi).

Fig. 7 ***Exposures of INR from surface burst (in roentgens)***

Overpressure	315 (45)	105 (15)	77 (11)	42 (6)	10 (1.5)	5 (0.75)
100 KT	300,000	20,000	9000	500	<1	<1
1 MT	70,000	1,000	250	2	<1	<1
10 MT	20,000	15	<1	<1	<1	<1
20 MT	9,000	1	<1	<1	<1	<1

Exposure would be lower from air bursts of the same weapon power. The figures given refer to thermonuclear weapons with 50 per cent fission yield. These figures may vary from 25 per cent to 150 per cent of the values given in the chart.

2. Shielding for INR

INR has greater energy and penetration than the radiation from fallout. The intensity of both INR and fallout radiation are reduced in proportion to the density of the shielding material. This can be expressed in terms of the 'half-value thickness' which is the thickness of a particular shielding material required to halve the radiation dose-rate. The approximate half-value thicknesses of some shielding materials against INR are given in Fig. 8.

Fig. 8 ***Half-value thicknesses of shielding materials***

	Against INR mm	(inches)	Against fallout radiation mm	(inches)
Steel	38	(1.5)	18	(0.7)
Concrete	152	(6.0)	56	(2.2)
Earth	190	(7.5)	84	(3.3)
Water	330	(13.0)	122	(4.8)
Brickwork	157	(6.2)	71	(2.8)

The half-value thicknesses of these materials against fallout radiation are given for comparison. They will be referred to later.

3. Slant incidence of INR

Most of the INR from a nuclear explosion arriving at a given point comes in a direct line from the fireball. There is a certain amount of scattering known as 'skyshine' which means that some initial gamma radiation might be received by a person shielded by a barrier from the light and heat flash (see Fig. 10). The amount of scattering of initial gamma radiation depends upon a number of factors, but probably amounts to about 10 per cent of that in the main beam. This means that though an underground or semi-sunk shelter might be shielded from the major part of the initial gamma radiation a certain amount could be received through the roof or sides of the shelter (if semi-sunk) by what is known as 'angular distribution'. However this benefit of shielding by nearby buildings cannot be taken into account in calculating the protection afforded by a shelter since the location of the source of the initial gamma radiation cannot be known.

4. Rate of emission of INR

The rate of delivery of initial nuclear radiation has some relevance to actions that might be taken immediately after a nuclear burst. Fig. 9 gives the percentage of initial gamma radiation dose received as a function of time for 20 KT and 5 MT air bursts. It can be seen that in the former case about 65 per cent and in the latter case 5 per cent of the total initial gamma radiation dose is received during the first second. In the case of the higher yield weapon it can be seen that if some shelter could be obtained within one second of seeing the explosion flash, such as by falling prone behind some substantial object, it could make the difference between life and death. Such an action would also help to prevent the translational effect of the blast.

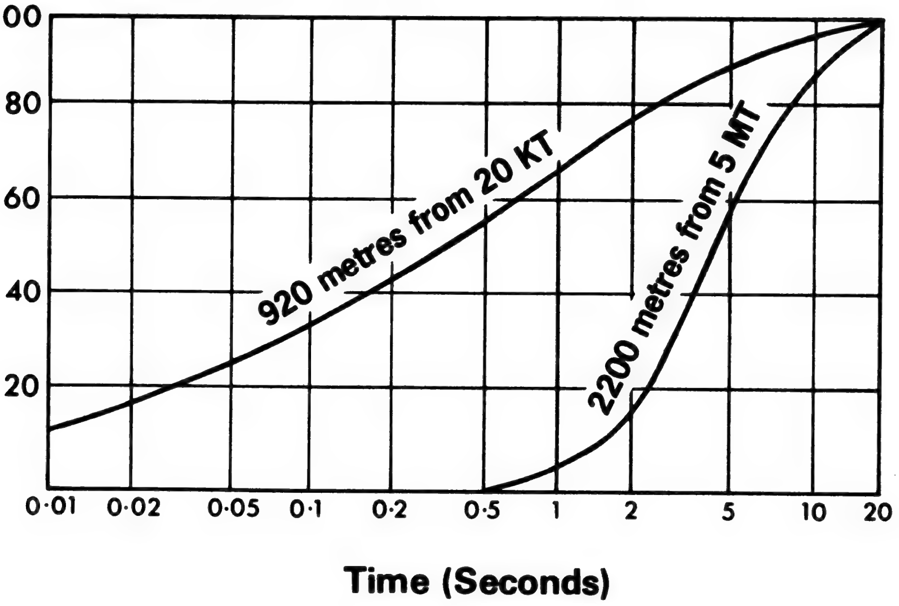
Residual radiation from fallout

Nature of fallout

Fallout from a groundburst weapon consists of molten and solidified particles of earth on to which the radioactive products of the detonation have condensed. It has the consistency of fine to coarse sand particles with size varying from 20 to 700 micrometres. Particles smaller than about 20 micrometres would most probably remain in the stratosphere and come down as late fallout weeks, months, or even years later; by this time their radioactivity would have decayed considerably. The fall times from various heights of particles of various sizes are given in Fig. 11.

The time taken for fallout to be deposited in any one place varies from about half an hour close to the explosion to many hours further downwind. It is particularly important that people get under some kind of cover during this period to avoid fallout particles getting on the skin. Anyone who is caught out during fallout deposition should certainly cover the head and exposed skin and remove the contaminated clothing before entering shelter. No special protective clothing is required since no kind of clothing will prevent the gamma radiation from fallout reaching the body. If anyone has to emerge from shelter after the fallout has been deposited on the ground it would be useful to wear waterproof boots and gloves with a coat over the indoor clothing. Again these should be removed before re-entering the shelter. Any exposed skin should be washed after any contact with fallout particles.

Fig. 9 ***Percentage of total initial gamma dose received***



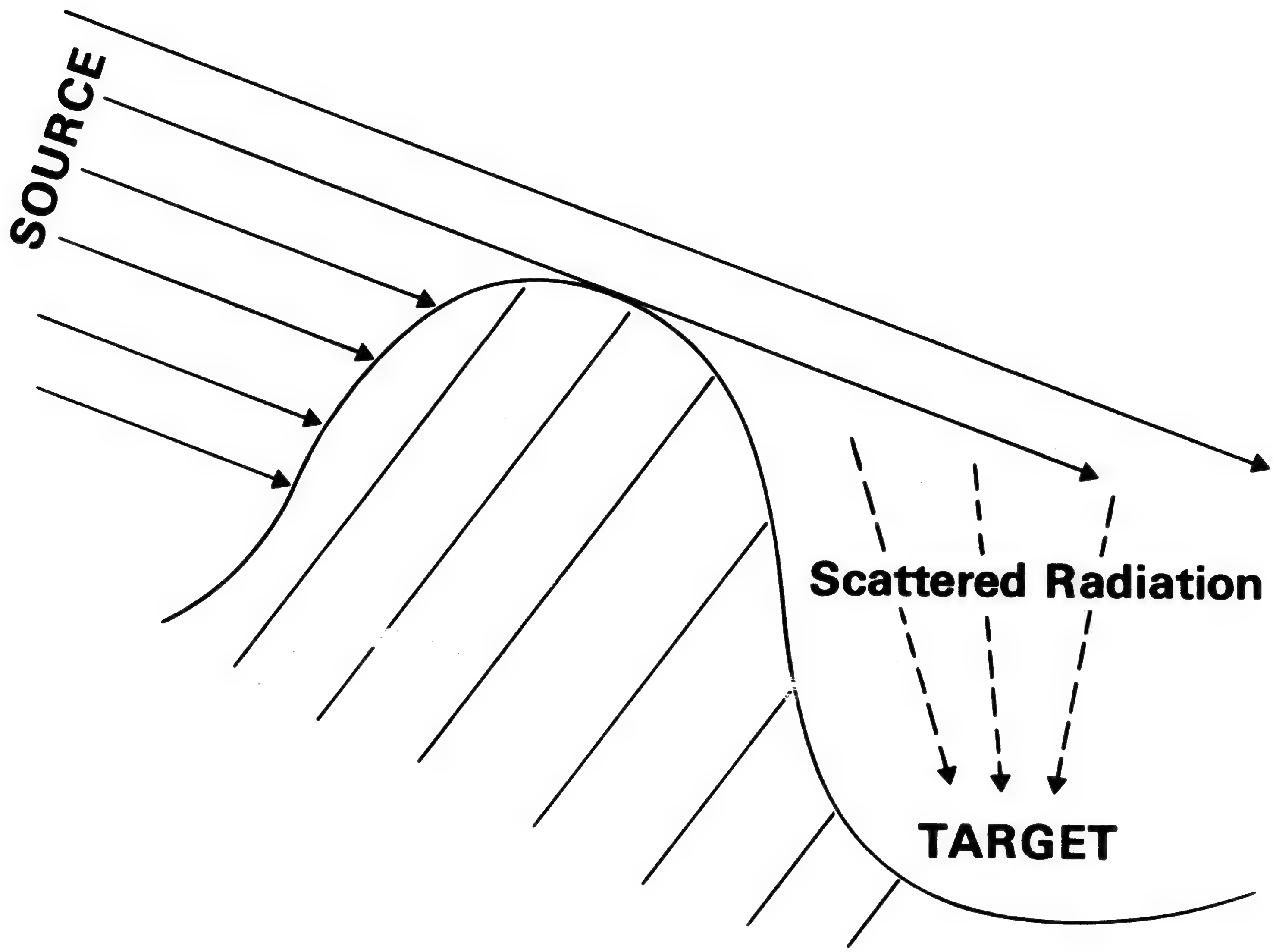


Fig. 10 ***Target exposed to scattered gamma radiation from a nuclear burst***

The nature of fallout particles has an influence on the filtration requirements for shelters. If the air coming into the shelter follows a tortuous path such as is provided by an inverted U shape or a cowl over the air intake, the need for filtration is minimised, if not entirely eliminated. The fallout particles will tend to fall to the earth rather than be carried along by the air current into the air duct. In any case the fallout particles are in the air for a limited period of time in the early hours after the burst so that if filtration is thought desirable, it need only be for that limited time. It would however be better to avoid drawing air into the shelter whilst the fallout is being deposited, if it is possible to know when this is taking place.

If a filter is incorporated into shelter design two points should be considered. The first is that a coarse filter is all that is necessary; a fine filter runs the risk of becoming blocked by ordinary atmospheric dust with resultant reduction of air supply. The second point is that if a filter is likely to become contaminated with radioactive dust then it should be placed outside the shelter.

Protection from fallout radiation

Protection against the radiation from fallout can be achieved in three ways. Consideration must be given to *duration* of exposure, *distance* from the fallout, and *density* of materials between the person and the fallout.

Duration. The damage caused by radiation to the body is cumulative (although the body does show a capability of some recovery). Thus it is important to reduce the time of exposure to radiation. In addition to this the radioactivity from fallout decays in a predictable manner by what is known as the '7/10 law'. Thus a dose rate of 1000 roentgens per hour at one hour after burst will decay to 100 roentgens per hour at seven hours after burst and 10 roentgens per hour at 49 hours (or two days) after burst and so on. This rapid decay means that, except in very severely contaminated areas, it is unlikely that anyone would have to stay continuously in shelter for two or three weeks. Local authorities will tell people when the intensity of the radiation has fallen to levels which make it safe to emerge from shelter for one or more hours. This time, which will gradually increase, can be used to ventilate the shelter better and attend to necessary tasks.

Distance. Protection can be achieved too by keeping as far away from the fallout as possible. A person standing on ground evenly contaminated by fallout would receive half his radiation dose from a circle of about 7.5 metres around him. Thus the floor of an underground shelter or a position in a house as far as possible from the roof and outside walls offers the best protection.

Density. The most important way of reducing the intensity of radiation is by sheltering behind some dense material. As explained, the level of radiation is reduced as it passes through any material but the greater the density of the material, the greater the reduction. The thickness of some materials required to reduce the intensity of fallout radiation to one half were given in Fig. 8. Glass gives little or no protection against radiation and many light materials, such as clothing, bedding etc., afford little protection. However, shelters can be constructed from such materials as glass reinforced plastic (GRP) which does not give much protection itself but can be buried in the ground; the earth cover then will give protection. A layer of 375 mm (15 inches) of earth or 250 mm (10 inches) of concrete over a shelter area would reduce the intensity of the radiation inside the shelter to 1/100th of the intensity outside. This reduction is called a protective factor (PF). A method for calculating protective factors is given in Chapter 2. It is designed for calculating the PFs of buildings. When applied to buried shelters the table dealing with penetration through the roof may be all that is needed.

Fig. 11 ***Time in hours for rough particles of different sizes to fall to the ground from specific heights***

Particle diameter in microns	500	350	200	100	75	50
Falling from metres (feet)						
25,000 (80,000)	1.6	2.3	4.5	12	22	49
18,000 (60,000)	1.3	2.0	3.7	9.5	17	36
12,000 (40,000)	1.0	1.5	2.8	6.8	12	25
9,000 (30,000)	0.8	1.2	2.2	5.3	9	19

Further comments on protection against INR and fallout radiation

From Fig. 7 it can be seen that a person on the outer edge the 'A' ring at 77 kPa (11 psi) from a one megaton explosion might receive a dose of about 250 rads INR. This would not in itself be lethal and even some rudimentary shelter would reduce the dose. At this same point the proportion of the population in houses surviving though injured might be about 40 per cent. Nearer to the point of burst the survivors would be fewer but the INR higher. It is in fact in the areas where blast shelters can give the greatest saving of life that INR becomes important, and so must be protected against. As a general rule, shelters designed to protect against 77 kPa (11 psi) and above should also give protection against INR. In most cases however, the required thicknesses of earth, concrete, etc. to give blast protection will also give the required INR protection.

Fig. 12 gives a comparison of the protective factors against INR gamma, neutrons and fallout radiation of some typical buildings. The data has been taken from *Effects of Nuclear Weapons* and the choice has been made of those buildings which are reasonably comparable with structures in the UK. The wide range of values is due partly to uncertainty in the data (since some have been calculated and others derived from weapons trials) and partly to the fact that protection to some extent is determined by the position in the building where the protective factor is measured.

Fig. 12 ***Protective factors of various buildings against initial gamma, neutron and fallout gamma radiation***

Structure	Initial gamma	Neutrons	Fallout gamma
1 metre underground	250–500	100–500	5000
Shelter partly above ground:			
with 600 mm earth	15–35	12–50	50–200
900 mm earth	50–150	20–100	200–1000

Further comments on Home Office shelter designs

Chapters 4 to 7 of this book give details of the Home Office shelter designs and, where appropriate, detailed instructions for construction. It will be useful however to discuss here the reasons why this range of shelters has been chosen. Other designs are under consideration and it is planned to make details of these available later.

Limitations related to houses and gardens

In making recommendations for shelters it has been necessary to keep in mind the varying needs governed by the types of housing in the United Kingdom. Very roughly housing can be divided into the following groups:

a. Detached or semi-detached houses where there is appropriate access to the rear garden. (About 34%).
b. Semi-detached and terrace housing where there is no access to the rear garden, except through the house. (About 20%).
c. Houses with no rear garden. Such houses usually have a passage between the rows of terraces with access to a back yard. (About 25%).
d. Multi-storey blocks of flats. (About 12%).
e. Flats resulting from the conversion of 2, 3 and 4 storey houses. There is usually some garden space available attached to such property. (About 7%).
f. Bungalows, usually with accessible gardens. (About 2%).
g. Caravans.

The shelter types in Fig. 13 are designed for use in these housing groups as follows:

Type 1 Groups a, b, c, f, possibly d, e and g.
Type 2 Groups a, b, c, f, possibly d.
Type 3 Groups a, b, f, possibly e.
Type 4 Groups a and f.

It will be seen that all groups of housing are covered except possibly for d and only minimally for e and g. Further consideration will be given to shelter provision for those in group d and also upper storeys of group e. However, we believe that one or more of our shelter types will be suitable for installation in the majority of the houses in the country.

Type 1 shelters

A 'core shelter' for use inside a house has already been described in ***Protect and Survive.*** Its life-saving potential should not be minimised. The details of the two improvised shelters in Fig. 13 are given in later chapters. The construction of these shelters has been carried out by volunteers satisfactorily. They were given a short time to read the instructions before carrying out the work. Although these are all designated improvised shelters, some thought can be given in advance to the procurement of materials for their construction, thereby eliminating the need to remove doors, etc. from the house.

Type 2 shelters

This type is designed for houses where there is no suitable ground attached to the house on which to install a shelter. It is in essence a 'core shelter' which will protect the occupants from the debris of a house that is severely damaged. The radiation protection factor is obtained by shielding it with bricks, blocks, sand, furniture, books, bags of soil, etc. It is designed to withstand the debris from a two- or three-storey house falling on it. However, it is probable that the debris from a three-storey house may make it difficult for the occupants to dig themselves out. The 'blast protection' indicated is that at which most houses would receive irreparable damage and there would be a considerable amount of debris on the shelter.

The details of this shelter are given in Chapter 5. This is not the only possible shape; further studies are underway which should result in different designs of the 'Indoor kit-type' shelter.

Chapter 5
Indoor kit shelter design

"Morrison shelter" of 1941 (indoor steel table shelter)

General

This chapter gives information about an indoor shelter suitable for erection in homes that have basements or rooms that can be converted into a fallout room. It can be used as the 'inner refuge' referred to in the Home Office booklet *Protect and Survive* and anybody considering purchasing or using such a shelter should read *Protect and Survive* and be totally familiar with its contents.

The shelter will accommodate two adults and two small children. Two or more shelters can be placed together to gain more shelter area.

It should be stored in a clean dry place, ready for erection if required, *and could be used for other purposes, e.g. a workbench in a garage or garden shed.*

Shelter details

The indoor kit-type shelter is shown in Fig. 64.

A specialist steelwork fabricator will need to cut, weld, paint and drill bolt holes for the steel parts. However, once the units have been manufactured the shelter can be erected by unskilled labour. (Two persons two hours each.) Steelwork shop fabrication drawings are given in section 5.11, a steelwork specification in 5.10 and a guide to putting up the shelter in 5.12.

The basic unit has been designed to be capable of sustaining the debris load resulting from the complete collapse of a typical two-storey house, and when surrounded with brickwork, sandbags or other protective materials it will provide good protection against fallout.

Location of shelter

Where the shelter can be used

In two-storey houses and the lower floors of blocks of flats of substantial reinforced concrete or steel-framed construction, in areas where the density of building is comparatively low.

Where the shelter should not be used

1. Houses that have more than two storeys.
2. On the upper floors of houses or any ground floor that has a basement directly below it.
3. Blocks of flats having load bearing brickwork, blockwork or precast concrete panel construction.
4. The top two floors of a block of flats.
5. Lightly clad buildings.

Location of shelter in fallout room

As explained in *Protect and Survive* the shelter should be placed within the fallout room. Choose the place furthest from the outside walls and from the roof, or the room which has the smallest amount of outside wall or openings. The entrance should be positioned facing a solid internal wall wherever possible (see Fig. 65). A gap of 600 mm should be left between the outside of the fallout protection around the shelter and the walls of the fallout room to facilitate emergency escape.

The shelter should be placed on the most solid base available. When the shelter is to be placed on a suspended ground floor, this floor may require strengthening by providing additional piers, walls or props to support the floor joists.

Protecting the shelter against fallout radiation

Fallout protection to the shelter can be obtained by surrounding it with dry-laid brickwork, blockwork, sandbags, or heavy furniture filled with sand, earth or books (see Figs. 66 and 67). Recommended thicknesses of shielding materials are given in the following table:

Fig. 61 ***Recommended thicknesses of shielding materials***

	Thicknesses		
	To sides		To top
	Sides facing external walls	Sides facing solid internal walls	
Brickwork	1½ bricks (343 mm)	1 brick (225 mm)	4 courses bricks (260 mm)
Dense blockwork	1½ blocks (330 mm)	1 block (225 mm)	3 courses blocks (300 mm)
Sandbags	350 mm	250 mm	300 mm

If bricks or blocks are used they should be dry-laid, but closely packed and bonded so as to stagger the joints as much as possible. Suggested bonding is shown in Fig. 68.

Fallout room
External windows and doors in the room containing the shelter should be blocked up with material of the same weight as the surrounding wall. A 600 mm by 600 mm dry-laid area should be left within the blocked-up area to provide an escape exit.

For shelters protected as described, protective factors are given in the following table:

Fig. 62 *Approximate protective factor*

House type	Protective factors	
	House with all exterior windows blocked	House with exterior windows blocked plus shelter and bricks
Terraced: traditional	15	260
Terraced: modern	11	140
Semi-detached: traditional	12	210
Semi-detached: modern	9	130
Detached: traditional	10	180
Detached: modern	8	110

Provision of emergency escape tunnel

Materials

Use tables, doors and other items of heavy furniture to form an emergency escape tunnel. As for *ad hoc* shelters, other structural commodities might be utilised for building escape tunnels. Fig. 69 shows how scaffold poles could be used for the purpose.

Location of escape tunnel

The escape route should be planned so that it emerges near to an opening in an external wall. If external openings are blocked up, a weaker escape knock-out area (e.g. dry-laid bricks or blocks 600 mm by 600 mm) should be provided.

Tools and materials required

For construction

16 mm and 10 mm spanners (1 open, and 1 ring, of each).
Steel lever for lining up holes.
Work gloves.

For shelter

Recommended quantities of materials for fallout protection are given in the following table. (Figures in table for entrance shielding wall, but do not consider materials required for blocking up openings in external walls.)

Fig. 64 ***Indoor kit-type shelter***

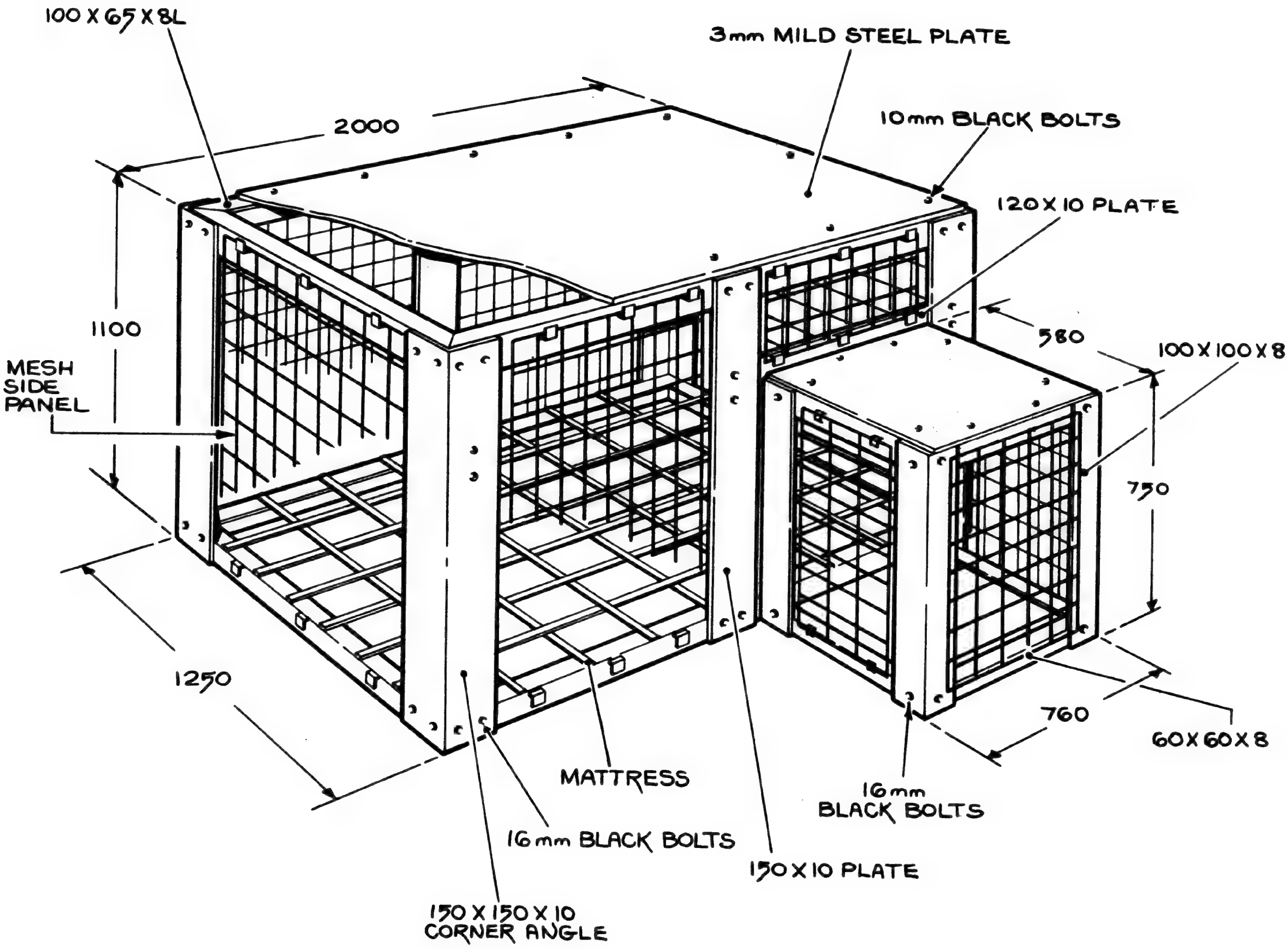
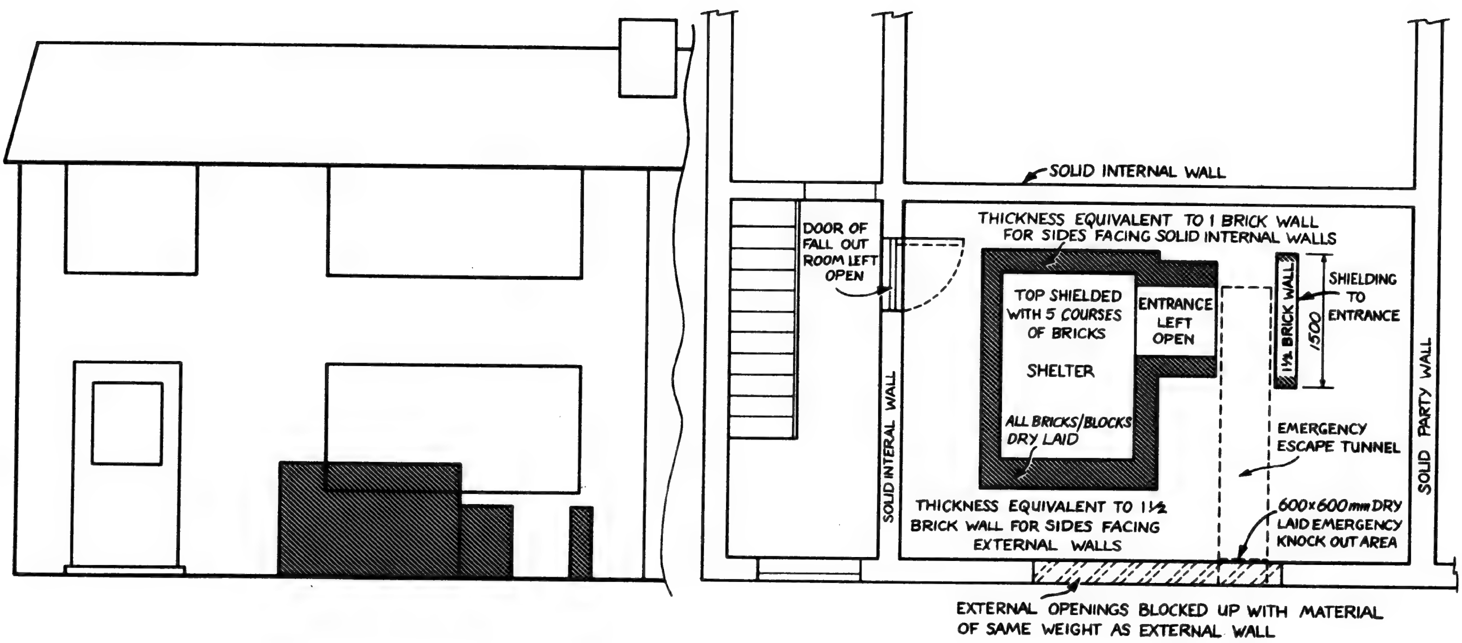


Fig. 65 ***Location of shelter***



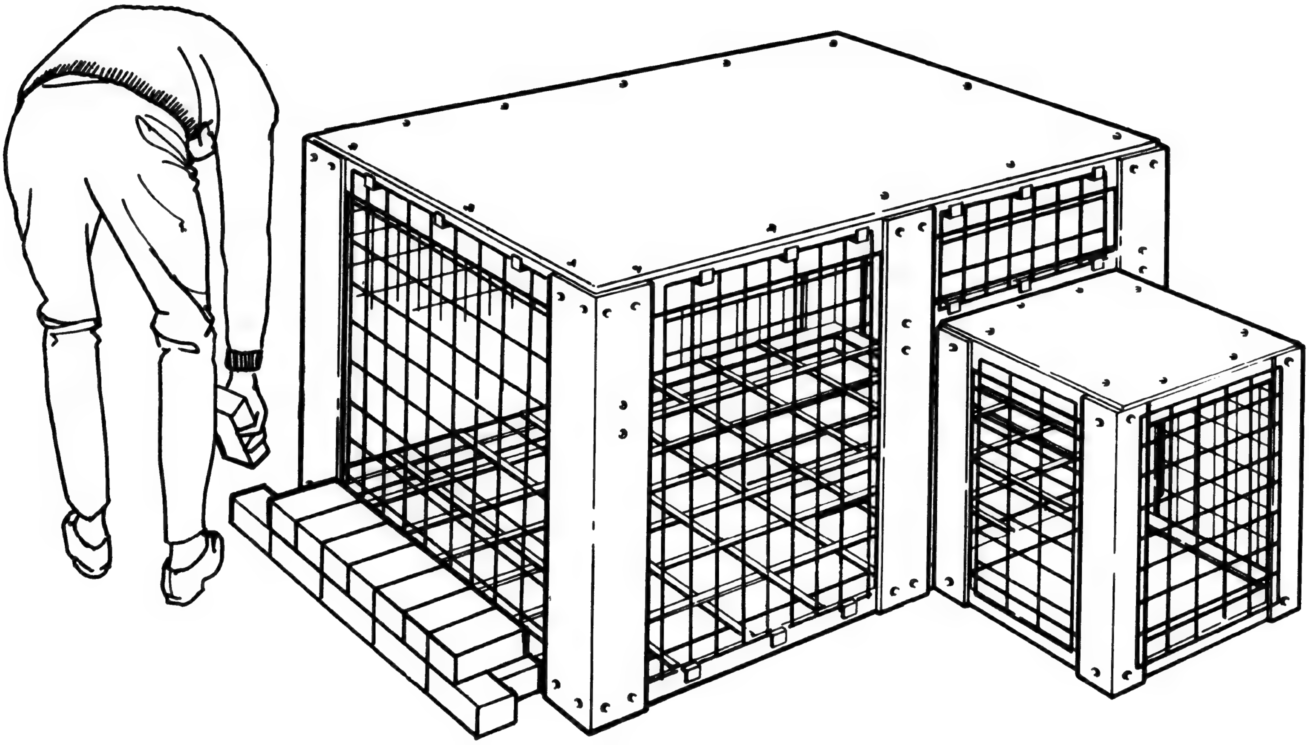


Fig. 66 ***Shelter surrounded with bricks***

Fig. 67 ***Shelter surrounded with sandbags***

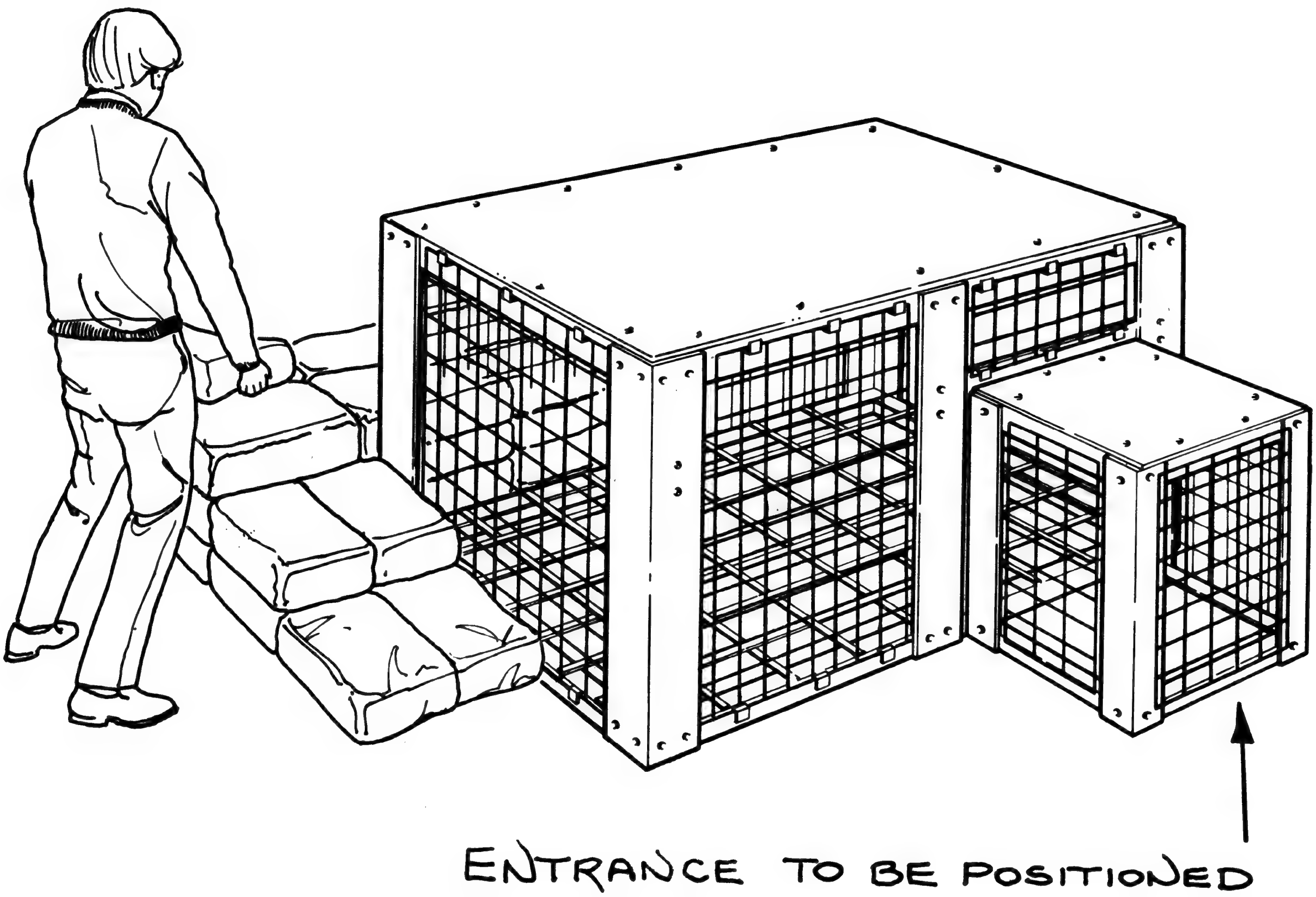
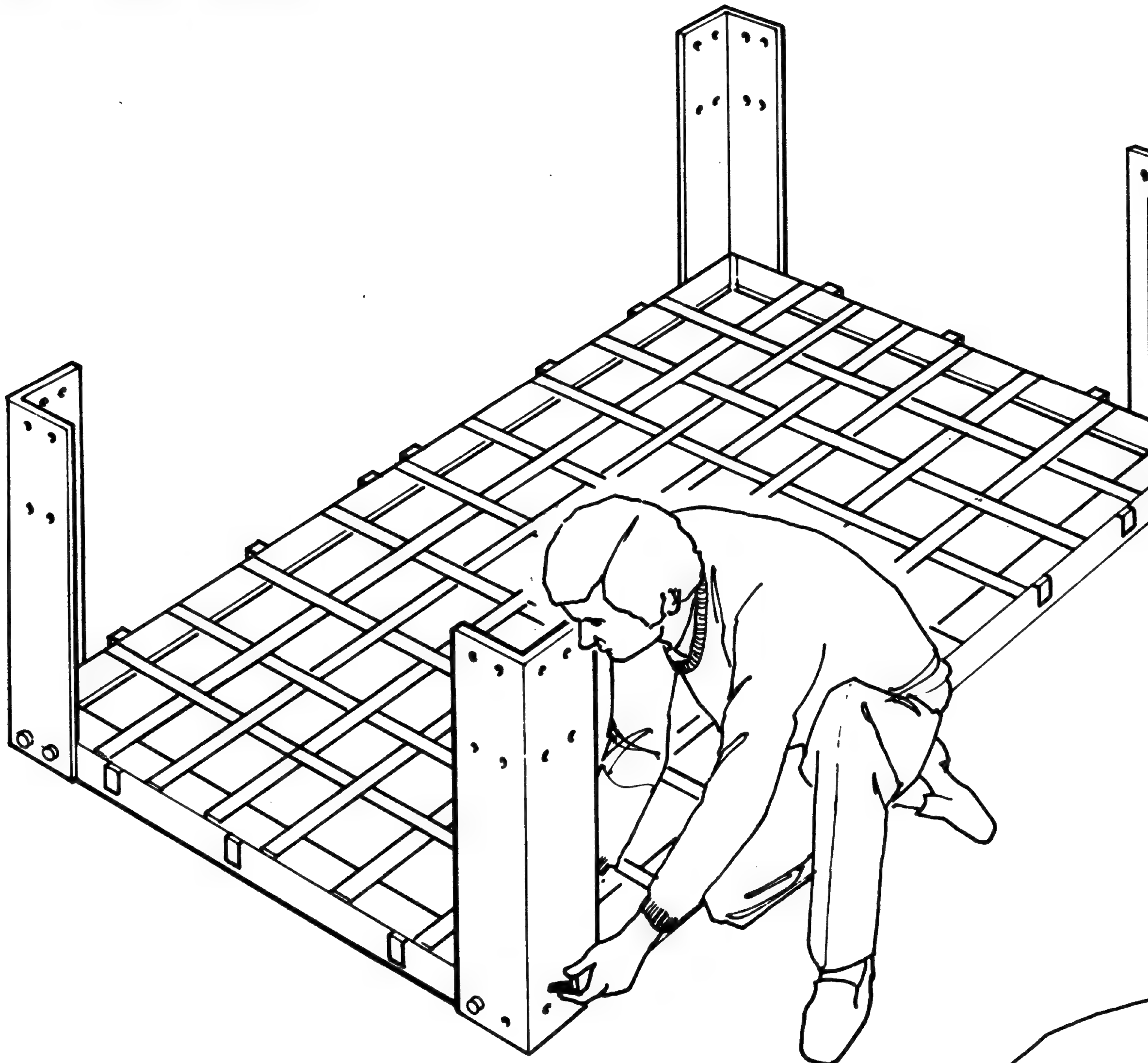


Fig. 79 *Erection drawings*



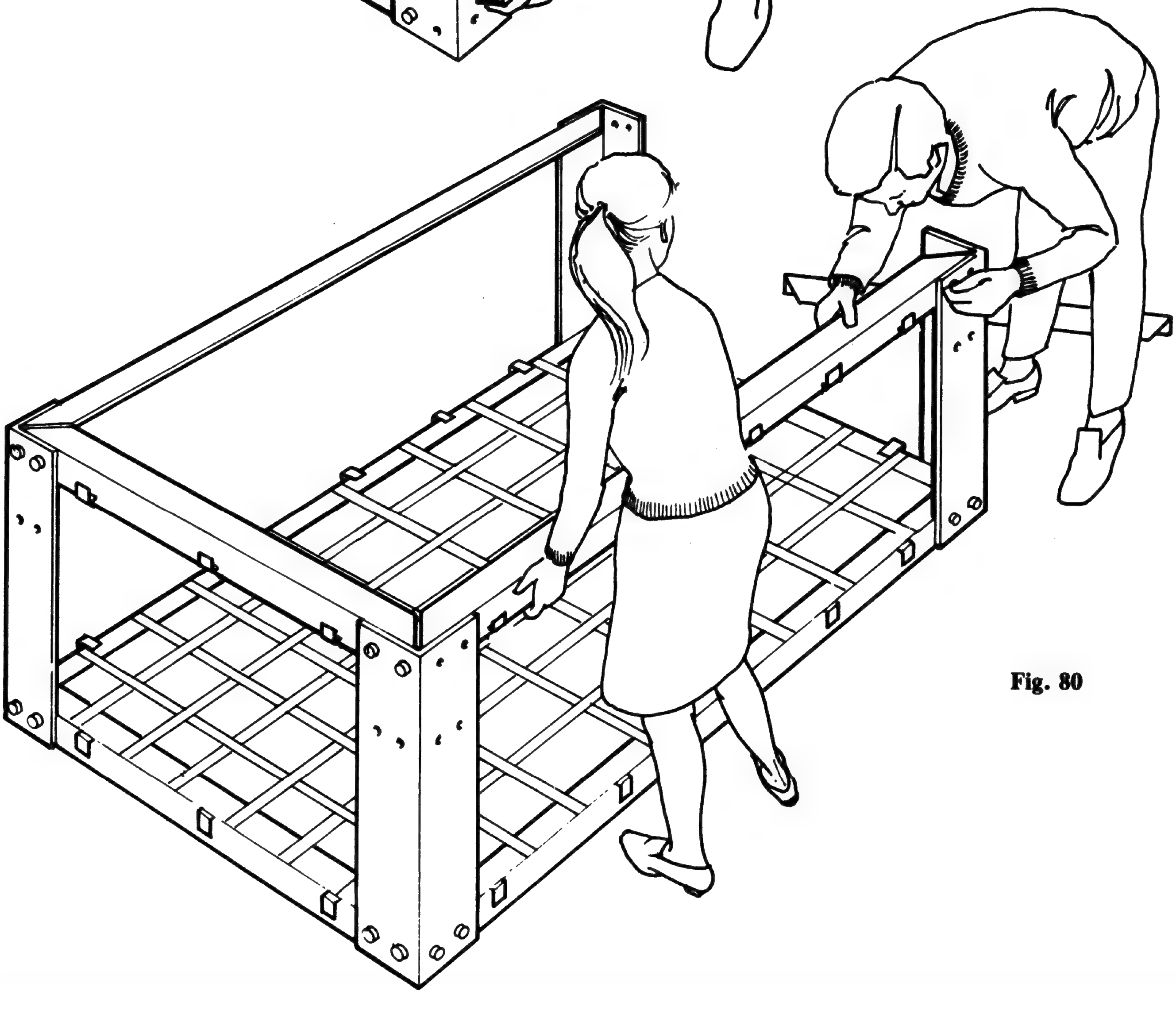


Fig. 80

Fig. 81

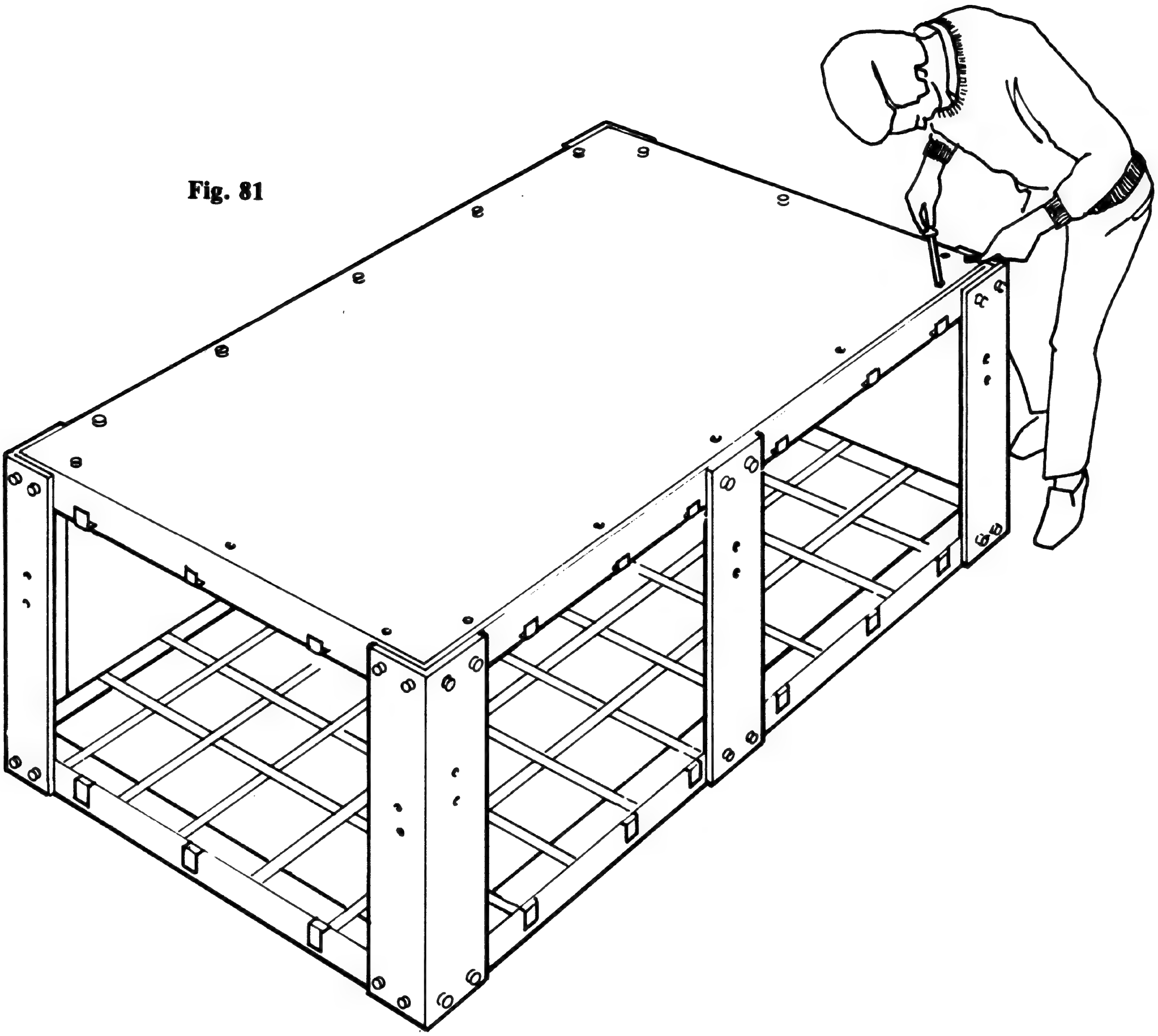
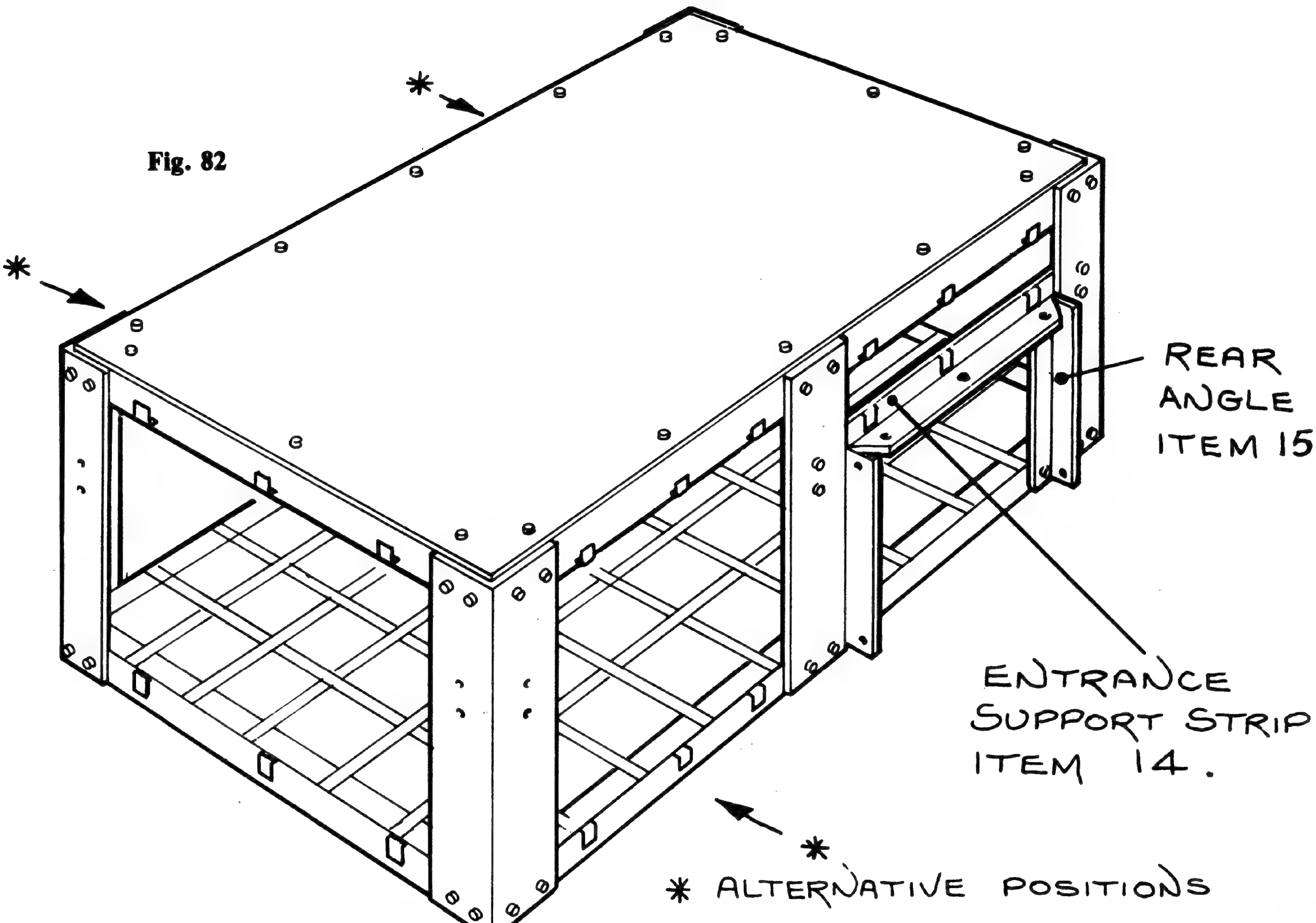
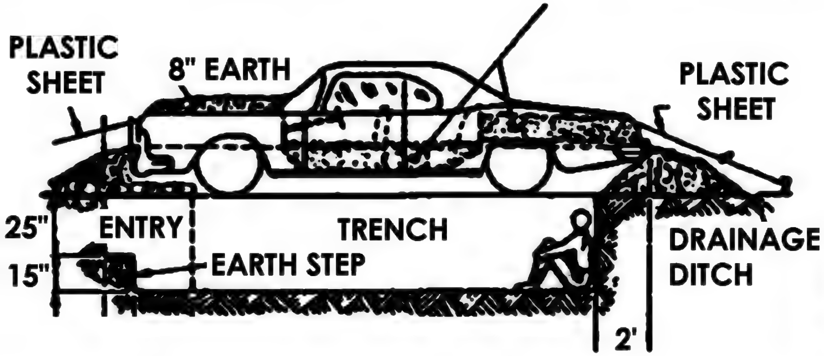


Fig. 82


*
*
REAR ANGLE ITEM 15
ENTRANCE SUPPORT STRIP ITEM 14.
*
* ALTERNATIVE POSITIONS

CAR-OVER-TRENCH FALLOUT SHELTER (EXPEDIENT SHELTER HANDBOOK)

COVER FLOOR AND TRUNK WITH PLASTIC SHEET
PLACE 1 FOOT OF EARTH ON FLOOR AND TRUNK



BANK EXCAVATED EARTH 20 INCHES HIGH AROUND CAR

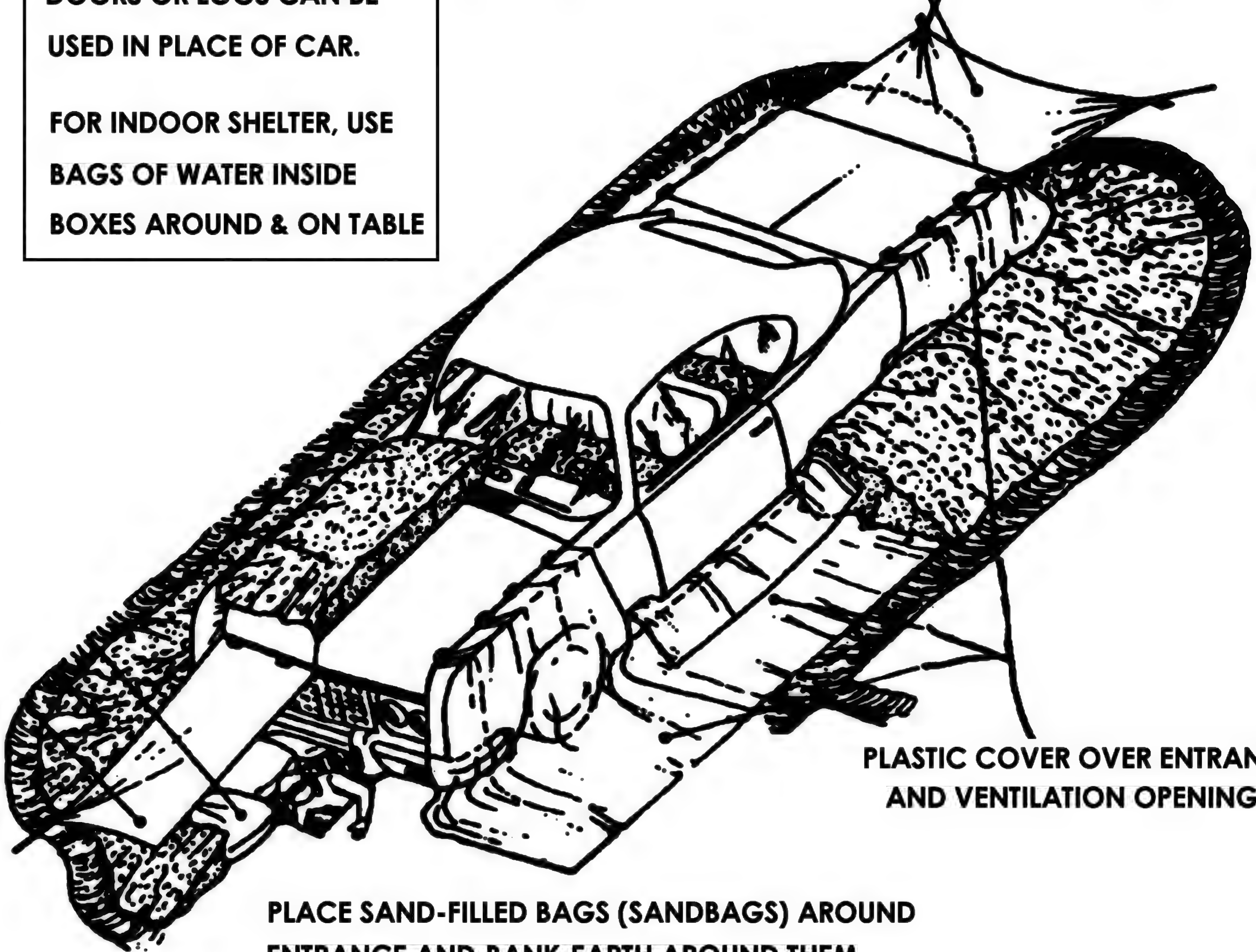
PLACE 8" OF EARTH ON CAR HOOD

DIG SHALLOW DRAINAGE DITCH AROUND FILL

DOORS OR LOGS CAN BE USED IN PLACE OF CAR.

FOR INDOOR SHELTER, USE BAGS OF WATER INSIDE BOXES AROUND & ON TABLE

PLASTIC COVER OVER ENTRANCE AND VENTILATION OPENINGS



PLASTIC COVER OVER ENTRANCE AND VENTILATION OPENINGS

PLACE SAND-FILLED BAGS (SANDBAGS) AROUND ENTRANCE AND BANK EARTH AROUND THEM

HOME OFFICE

THE PROTECTION OF YOUR HOME AGAINST AIR RAIDS

READ THIS BOOK THROUGH
THEN
KEEP IT CAREFULLY

Why this book has been sent to you

If this country were ever at war the target of the enemy's bombers would be the staunchness of the people at home. We all hope and work to prevent war but, while there is risk of it, we cannot afford to neglect the duty of preparing ourselves and the country for such an emergency. This book is being sent out to help each householder to realise what he can do, if the need arises, to make his home and his household more safe against air attack.

The Home Office is working with the local authorities in preparing schemes for the protection of the civil population during an attack. But it is impossible to devise a scheme that will cover everybody unless each home and family play their part in doing what they can for themselves. In this duty to themselves they must count upon the help and advice of those who have undertaken the duty of advice and instruction.

If the emergency comes the country will look for her safety not only to her sailors and soldiers and airmen, but also to the organised courage and foresight of every household. It is for the volunteers in the air raid precautions services to help every household for this purpose, and in sending out this book I ask for their help.

Samuel Hoare

HOW TO CHOOSE A REFUGE-ROOM

Almost any room will serve as a refuge-room if it is soundly constructed, and if it is easy to reach and to get out of. Its windows should be as few and small as possible, preferably facing a building or blank wall, or a narrow street. If a ground floor room facing a wide street or a stretch of level open ground is chosen, the windows should if possible be specially protected (see pages 30 and 31). The stronger the walls, floor, and ceiling are, the better. Brick partition walls are better than lath and plaster, a concrete ceiling is better than a wooden one. An internal passage will form a very good refuge-room if it can be closed at both ends.

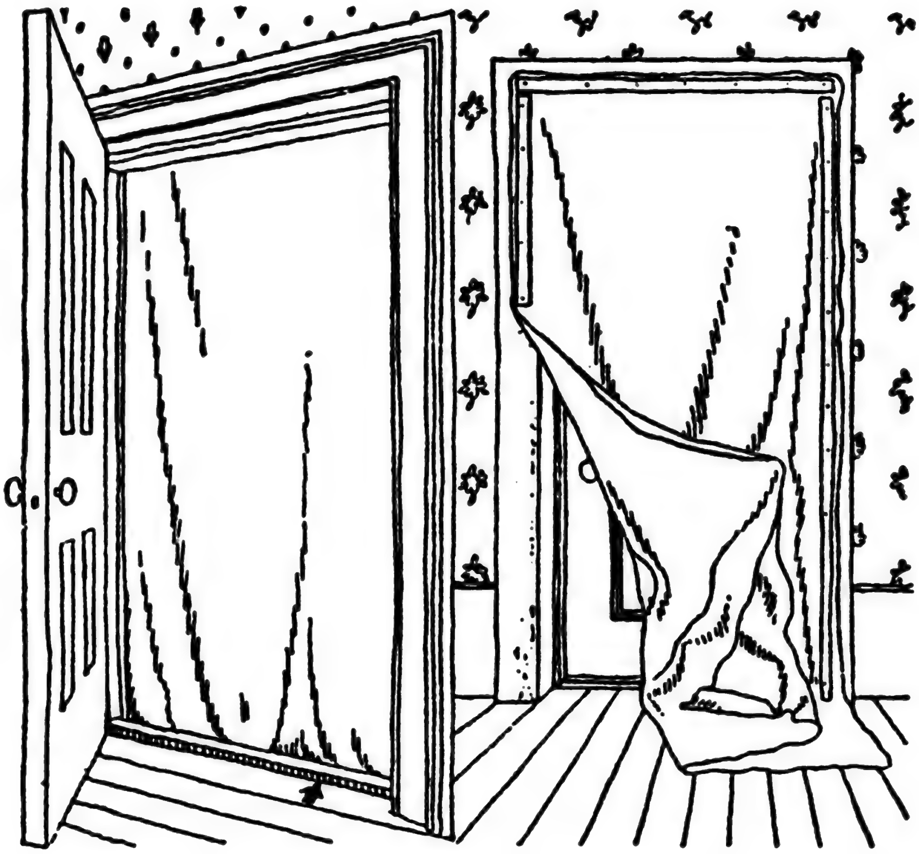
A cellar or basement is the best position for a refuge-room if it can be made reasonably gas-proof

The best floor for a refuge-room

A cellar or basement is the best place for a refuge-room if it can be made reasonably gas-proof and if there is no likelihood of its becoming flooded by a neighbouring river that may burst its banks, or by a burst water-main. If you have any doubt about the risk of flooding ask for advice from your local Council Offices.

Alternatively, any room on any floor below the top floor may be used. Top floors and attics should be avoided as they usually do not give sufficient protection overhead from small incendiary bombs. These small bombs would probably penetrate the roof but be stopped by the top floor, though they might burn through to the floor below if not quickly dealt with.

In a house with only two floors and without a cellar, choose a room on the ground floor so that you have protection overhead



How to seal up the door

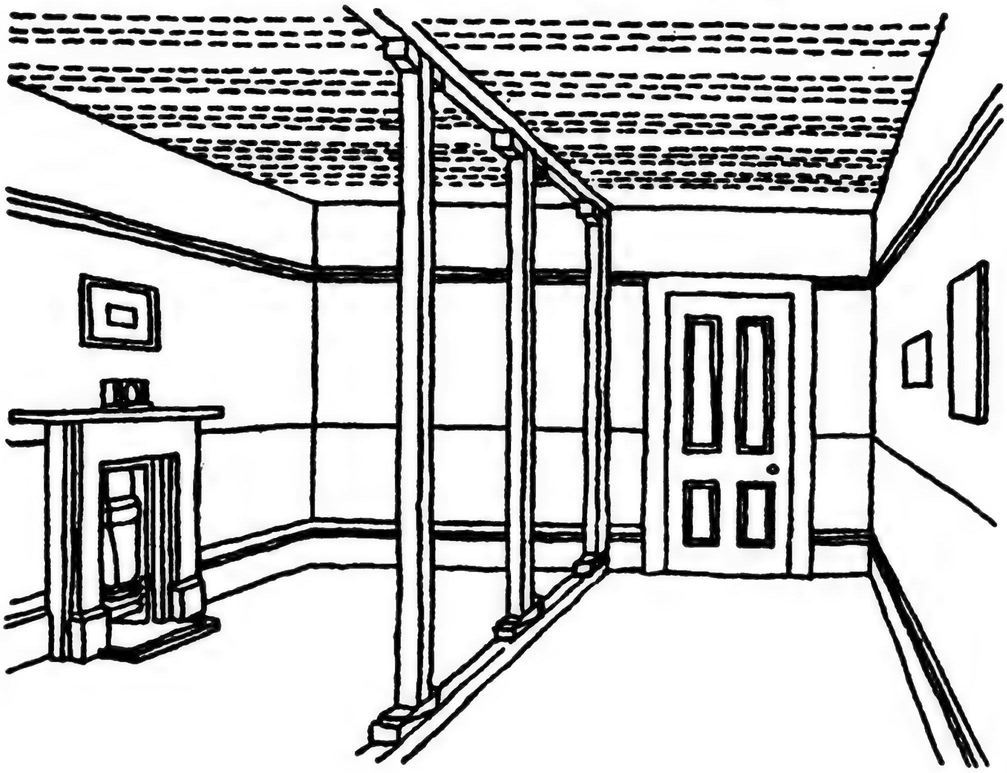
Doors which have to be opened and closed should be sealed against gas. This is how to do it.

Nail a piece of wood, padded with felt, to the floor so that the door, when closed, presses tightly against it. Take care not to nail this piece of wood on the wrong side of the door so that it cannot be opened. Strips of felt may also be nailed round the inside of the door to exclude draughts. Fix a blanket outside the door if the door opens inwards, or inside the door if the door opens outwards, with strips of wood. The top of the blanket should be fixed to the top of the door frame. One side of the blanket should be fastened down the whole length of the door frame, on the side where the hinges are, by means of a strip of wood nailed to the frame. The other side of the blanket should be secured not more than two feet down, so that a flap is left free for going in and out. Arrange the blanket so that at least 12 inches trails on the floor to stop air from blowing underneath it. See illustration above. If the blanket is kept damp during an air raid, it will give better protection.

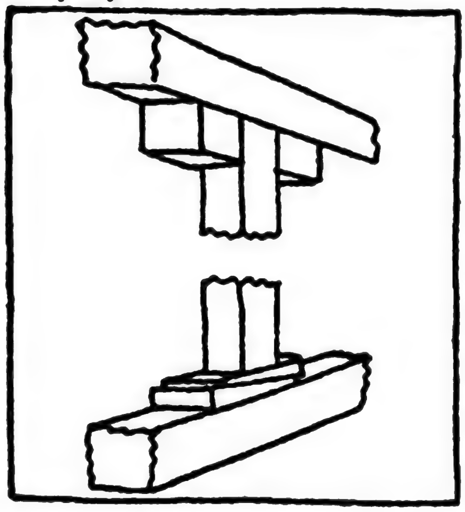
Strengthening the room

If your refuge-room is on the ground floor or in the basement, you can support the ceiling with wooden props as an additional protection. The illustration shows a way of doing this, but it would be best to take a builder's advice before setting to work. Stout posts or scaffold poles are placed upright, resting on a thick plank on the floor and supporting a stout piece of timber against the ceiling, at right angles to the ceiling joists, i.e. in the same direction as the floor boards above.

How to support a ceiling



The illustration below shows the detail of how to fix the props



The smaller illustration shows how the posts are held in position at the top by two blocks of wood on the ceiling beam. The posts are forced tight by two wedges at the foot, driven in opposite ways. Do not drive these wedges too violently, otherwise you may lift the ceiling and damage it. If the floor of your refuge-room is solid, such as you might find in a basement, you will not need a plank across the whole floor, but only a piece of wood a foot or so long under each prop.

How to deal with an incendiary bomb

You can tackle a small incendiary bomb yourself (better if you have someone to help you) if you will follow these directions. You will also be able to get proper instruction about it.

The bomb will burn fiercely for a minute or so, throwing out burning sparks, and afterwards less fiercely. It will set fire to anything inflammable within reach. You should try to deal with it before it has caused a big fire.

Before you can get close enough to do anything, you will probably have to cool down the room with water, preferably with a line of hose. (See page 20 for a simple hand pump.)

There are two ways of dealing with the bomb itself.

1. It can be controlled by means of the Stirrup Hand Pump (see page 20), with a *spray* of water which, although it does not extinguish the bomb, makes it burn out quickly and helps to prevent the fire spreading. Water must *not* be used on a bomb in any other way.

2. If it has fallen where you can get at it, it can be smothered with dry sand or earth. A bucket full of sand or earth is enough to cover and control a small bomb. The best method of applying it is by the Redhill sand container and scoop (see page 19); but a bucket will do if you have a long-handled shovel to use with it.

   Immediately the bomb is smothered, shovel or scoop it into the sand container or bucket and take it out of doors. If a bucket is used, 2 or 3 inches of sand or earth must be kept in the bottom to prevent the bomb burning through.

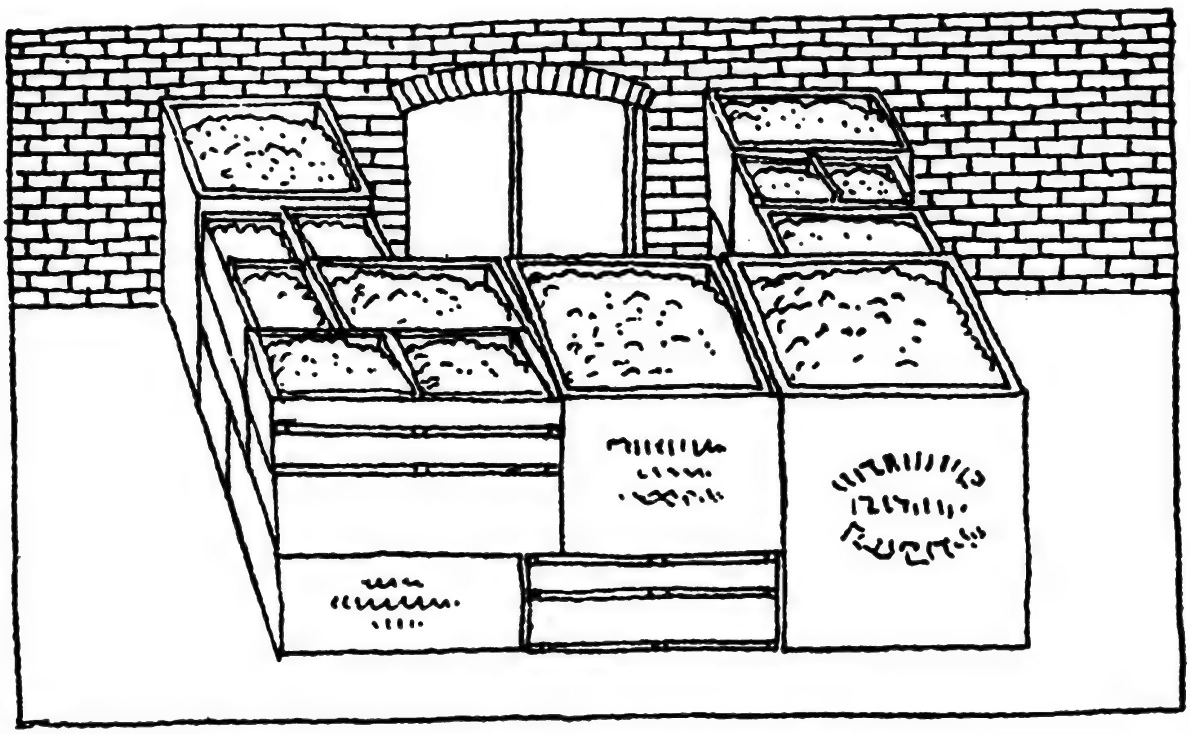
Remember that the bomb might burn through the floor before you have had time to remove it, and you might have to continue to deal with it on the floor below.

ACT PROMPTLY. PROMPT ACTION MAY BE THE MEANS OF SAVING LIVES. PROMPT ACTION WILL SAVE PROPERTY. PROMPT ACTION WILL PREVENT SERIOUS DAMAGE. PROMPT ACTION WILL DEFEAT THE OBJECT OF THE RAID.

EXTRA PRECAUTIONS AGAINST EXPLOSIVE BOMBS

TRENCHES. Instead of having a refuge-room in your house, you can, if you have a garden, build a dug-out or a trench. A trench provides excellent protection against the effects of a bursting bomb, and is simple to construct. Full instructions will be given in another book which you will be able to buy. Your air raid wardens will also be able to advise.

SANDBAGS. Sandbags outside are the best protection if your walls are not thick enough to resist splinters. Do not rely on a wall keeping out splinters unless it is more than a foot thick. Sandbags are also the best protection for window openings. If you can completely close the window opening with a wall of sandbags you will prevent the glass being broken by the blast of an explosion, as well as keeping out splinters. But the window must still be sealed inside against gas.



A basement window protected by boxes of earth

Any bags or sacks, including paper sacks such as are used for cement, will do for sandbags.

ALL persons involved in accidents suffer from shock, whether or not they suffer physical injury. Shock is a disturbance of the nervous system. It varies in its severity. The signs of shock are faintness, paleness, weak pulse, and weak breathing.

TREATMENT OF SHOCK

1 Place the patient flat on his back on a bed or a rug or on cushions. If you think a bone may be broken do not move the patient more than can be helped.

2 Loosen the clothing at the neck, chest and waist to make the breathing freer.

3 Cover the patient warmly with rugs and blankets. In cases of shock the body loses heat. A hot-water bottle is helpful, but take care that it does not lie in contact with the skin.

4 Give hot drinks. If you cannot make hot drinks, give cold water *in sips*. But only if the patient is conscious and able to swallow.

5 Soothe the patient by speaking reassuring words in a calm voice and in a confident way.

TREATMENT OF WOUNDS

The first thing to do is to stop the bleeding and to keep the wound clean. This can be done by covering it with a clean dressing bound on tightly. Do not touch a wound with your fingers because of the risk of poisoning from dirt. Treat the patient for shock in addition to attending to the wound, because the loss of blood, if the wound is serious, and the pain do in themselves cause shock.

WOUNDS IN THE HEAD AND BODY

1 Cover the wound with a clean folded handkerchief or a double layer of dry lint.

2 Apply another handkerchief or a layer of cotton wool as a pad to distribute the pressure over the wound.

3 Tie the dressing in position with a bandage, a strip of linen, or a necktie. This can be done quite firmly, unless there is any foreign body, especially glass, in the wound, or unless the bone is broken. In this case the dressing should be tied on lightly.

4 Treat the patient for shock.

ornl

OAK RIDGE
NATIONAL
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ORNL/TM-10423

Technical Options for Protecting Civilians from Toxic Vapors and Gases

C. V. Chester

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OPERATED BY
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FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Table 1. Chemical Agent Toxic Properties[1]

Agent	Volatility (mg/m^3, 25^oC)	Median Lethal Concentration X Time (mg/m^3 *min)		Median Incapacitation Concentration X Time
		Respiratory	Percutaneous	(mg/m^3 *min)
Chlorine (CL)	2.2 X 10^7	19,000	-	1,800
Phosgene (CG)	4 X 10^6	3,200	-	1,600
Hydrogen Cyanide (AC)	1 X 10^6	2,000-4,500	-	>2,000
Cyanogen Chloride (CK)	1 X 10^6	11,000	-	7,000
Sulfur Mustard (HD)[2]	920	1,500	10,000	200
Nitrogen Mustard (HN-1)	2,000	1,500	20,000	200
Lewisite (L)[2]	6,000	1,200-1,500	100,000	300
Mustard Lewisite (HL)	4,200	1,500	>10,000	200
Tabun (GA)[2]	610	400	40,000	300
Sarin (GB)[2]	22,000	100	15,000	35-75
Soman (GD)	3,900	100	1,000	35-75
VX[2]	10.5	100	1,000	50
Methyl Isocyanate		1500		

[1]Taken from U.S. Department of the Army (1975) and WHO (1970).

[2] Chemical agents in the stockpile to be destroyed in this program.

DISTANCE AND ATMOSPHERIC DISPERSION

As a toxic cloud moves downwind it mixes with ever increasing amounts of air, becoming larger and more dilute. Diffusion of the vapor vertically and at right angles to direction of motion reduces the exposure to someone standing in the path of the cloud. Diffusion forward and backwards along the direction of travel in general does not reduce the amount inhaled by someone in the path of the cloud.

The rate of vertical and lateral mixing of the toxic cloud with the surrounding air can vary enormously depending on weather conditions. A bright, sunshiny day promoting convection of the atmosphere close to the ground will cause rapid vertical mixing. A turbulent wind will promote lateral mixing. High windspeeds also reduce the time that a person is immersed in a passing cloud and directly reduces the amount they will inhale for given quantity going by. The worst conditions providing the greatest threat to people at the greatest distance downwind occur under conditions of light, steady winds, a clear night with cooling of the ground to cause vertical stability in the atmosphere and the existence of a temperature inversion not too far above the ground to trap the chemical close to the ground. Conditions very close to these were responsible for the large casualties at the Bhopal incident in India.

Figure 1 shows the downwind hazard from clouds of 1000 kilograms of each of several toxic gases moving at 1 meter per second (approx. 2 miles per hour) in a highly stable atmosphere (Pasquill type E). These conditions also assume an inversion at 750 meters. Calculations use the Army's D2PC code (Whitacre et al, 1986). The dependent variable in Fig. 1 is given as the protection factor offered by protective measures required to prevent 99 percent of the fatalities at each location downwind. For example for GB, to keep the dose down to 1 percent fatalities at 1 kilometer downwind, the population would have to have masks or other protection giving a protection factor of a little less than 700. The

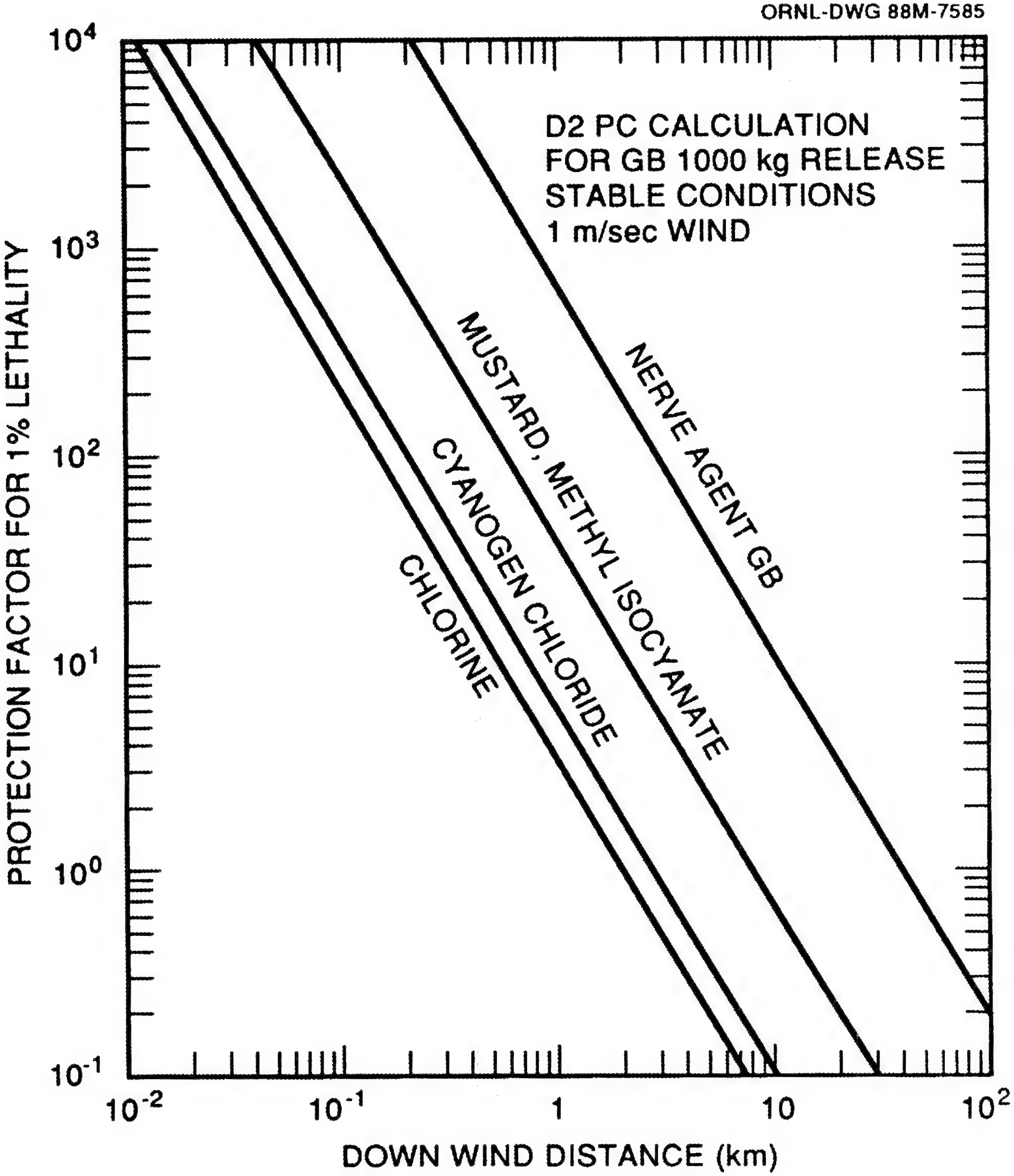

Fig. 1 Dose vs Downwind Distance for Some Very Toxic Gases

protection factor is the ratio of the dose people would get with no mask compared to what they would get if they were wearing a gas mask.

As can be seen from Fig. 1 the requirement for gas masks diminishes rapidly as one gets further away from the point of release of a quantity of agent. Under sunny conditions with a higher wind speed the requirement for protection would decrease even more rapidly. For the purposes of this study, these relatively pessimistic meteorological conditions (1.0 m/s. wind velocity, type E stability, inversion at 750 m) will be assumed in all cases.

EVACUATION

Evacuation is a way of increasing the distance between the population and a hazard and is the countermeasure to toxic chemical releases with which there is the most experience. Sorensen and his colleagues have reviewed the subject thoroughly (1987). It is very effective for slowly (few hours) developing hazards and in areas where emergency plans employing evacuation have been developed. Slowly developing chemical hazards can include a relatively small leak of a volatile toxic chemical, a large spill of a low volatility but highly toxic substance, or a progressive accident (e.g. fire) which doesn't at first cause release of toxic chemicals but has the potential of spreading to nearby equipment, tanks or drums containing toxics. Where small areas are threatened, evacuation can be quite effective.

Situations where taking shelter may be preferable to evacuating include quick release of small quantities of volatile toxic chemicals, or circumstances where an evacuation is likely to result in a traffic jam. This latter is a possibility where the area at risk is large, the population density is high, and the time available is short.

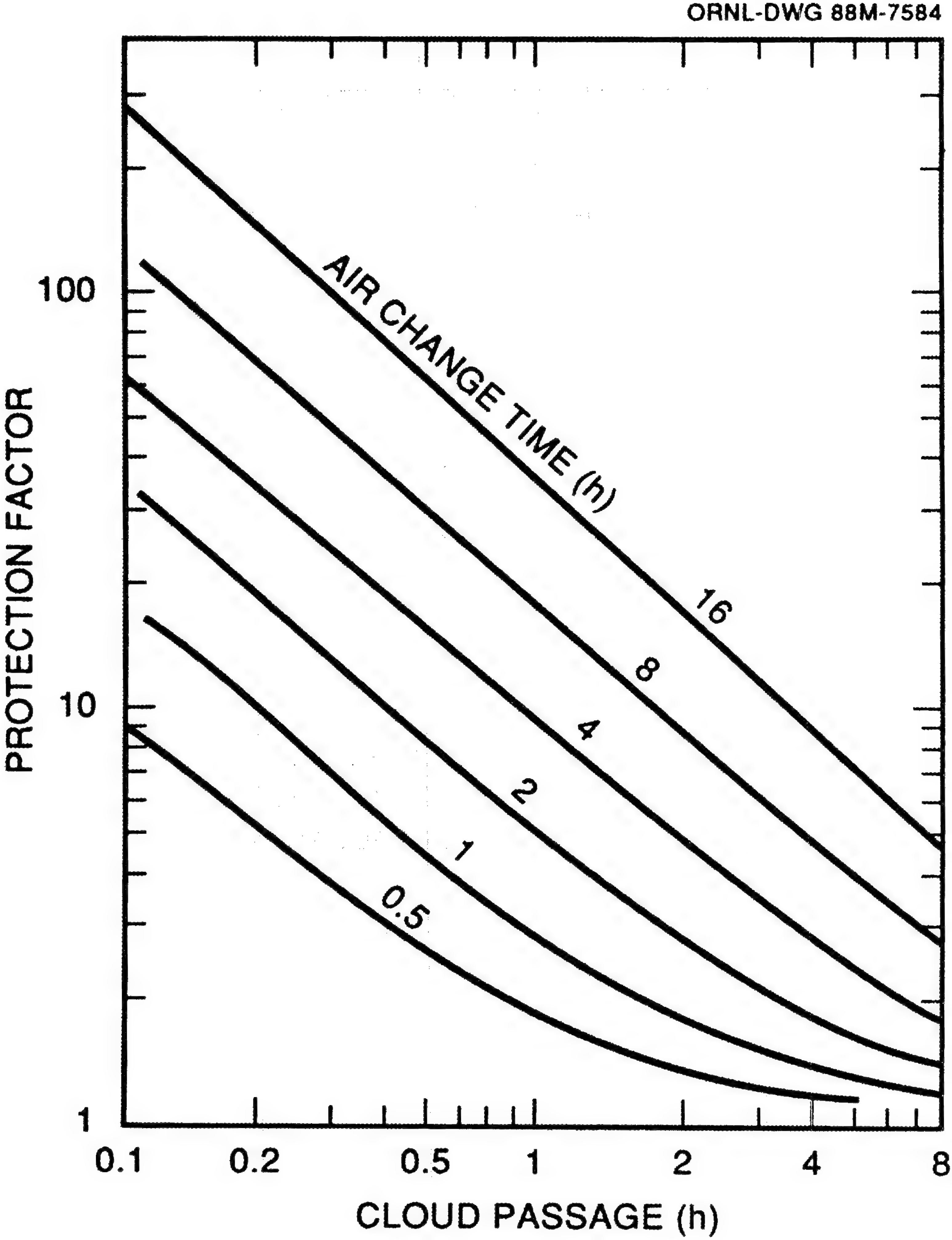

Fig. 2 Protection Factor of Leaky Enclosures

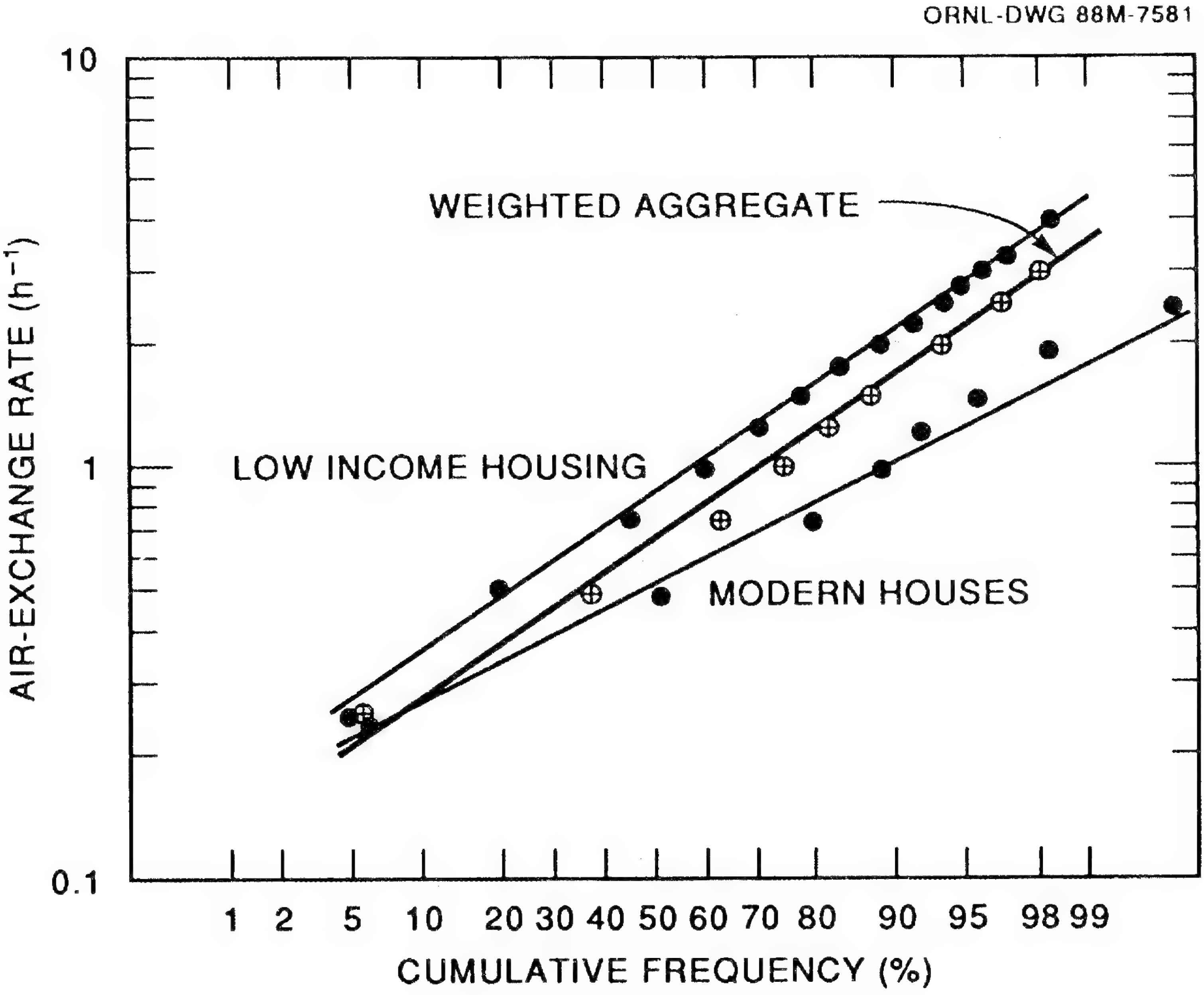

Fig. 3 Infiltration Rates of American Residences

Sorensen, J.H., 1988, Evaluation of Warning and Protective Action Implementation Times for Chemical Weapons Accidents, ORNL-TM/10437, Oak Ridge National Laboratory, Oak Ridge, TN 37831.

U.S. Department of the Army 1975, Military Chemistry and Chemical Compounds, FM3-9/AFR 355-7.

Whitacre, G.C. et al, Personal Computer Program for Chemical Hazard Prediction (D2PC), U.S. Army Chemical Research and Development Center, Aberdeen Proving Ground, MD.

Wilson, D. J. 1987, Stay Indoors or Evacuate to Avoid Exposure to Toxic Gas, Emergency Preparedness Digest (Canada) 14 no. 1.

World Health Organization, 1970, Health Aspects of Chemical and Biological Weapons, Geneva, Switzerland.

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Energy Division

Will Duct Tape and Plastic Really Work? Issues Related To Expedient Shelter-In-Place

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Barbara M. Vogt

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Expedient sheltering involves the use of common materials to enhance the safety of a room inside a building against the impacts of a chemical plume. The central premise behind taping and sealing with duct tape and plastic is to reduce airflow into a room. Vapors penetrate into a room through cracks and openings in the walls, floors and ceilings, around doors and windows, and through openings for ducts, light fixtures, fans, pipes, electrical outlets, chimneys, door handles, and locks. The goal of taping and sealing is to significantly reduce infiltration at these points.

Expedient sheltering was suggested by NATO (1983) using the term “ad-hoc shelter” to protect civilian populations from chemical warfare agent exposure. The concept was to use plastic sheeting to seal off a room by fashioning a simple airlock at the entrance to the room and sealing off doors, windows or louvered vents. The NATO guidelines also stressed the need for rapid exit from the ad-hoc shelter once the plume had passed to avoid further exposure (NATO 1983, p. 143).

This strategy was further developed by the Israeli Civil Defense in the mid-1980s to protect the public against a chemical weapons attack (Yeshua 1990). The tape and seal strategy was in place when the Gulf War occurred in 1991 and received considerable media attention. The Israeli strategy was to have citizens prepare a “safe room” in their house or apartment with the use of weatherization techniques to permanently reduce infiltration. Citizens were also instructed to take expedient measures, such as sealing doors and windows with plastic sheets, in the event of a chemical weapons attack. The use of plastic over a window was developed to reduce air infiltration and to provide a vapor barrier in the event of glass breakage from bomb explosions. A modification of the Israeli strategy was proposed for use in CSEPP (Sorensen 1988; Rogers et al. 1990).

Although vapors, aerosols, and liquids cannot permeate glass windows or door panes, the amount of possible air filtration through the seals of the panes into frames could be significant, especially if frames are wood or other substance subject to expansion and contraction. To adequately seal the frames with tape could be difficult or impractical. For this reason, it has been suggested that pieces of heavy plastic sheeting larger than the window be used to cover the entire window, including the inside framing, and sealed in place with duct or other appropriate adhesive tape applied to the surrounding wall.

Another possible strategy would be to use shrink-wrap plastic often used in weatherization efforts in older houses. Shrink-wrap commonly comes in a 6 mil (0.006-in.) thickness and is adhered around the frame with double-faced tape and then heated with a hair dryer to achieve a tight fit. This would likely be more expensive than plastic sheeting and would require greater time and effort to install. Because double-faced tape has not been challenged with chemical warfare agents, another option is to use duct tape to adhere shrink-wrap to the walls. Currently, we do not recommend using shrink-wrap plastics because of the lack of information on its suitability and performance.

3. WHY WERE THESE MATERIALS CHOSEN?

Duct tape and plastic sheeting (polyethylene) were chosen because of their ability to effectively reduce infiltration and for their resistance to permeation from chemical warfare agents.

3.1 DUCT TAPE PERMEABILITY

Work on the effectiveness of expedient protection against chemical warfare agent simulants was conducted as part of a study on chemical protective clothing materials (Pal et al. 1993). Materials included a variety of chemical resistant fabrics and duct tape of 10 mil (0.01-in.) thickness. The materials were subject to liquid challenges by the simulants DIMP (a GB simulant), DMMP (a VX simulant), MAL (an organoposphorous pesticide), and DBS (a mustard simulant). The authors note that simulants should behave similarly to live agents in permeating the materials; they also note that this should be confirmed with the unitary agents. The study concluded that "duct tape exhibits reasonable resistance to permeation by the 4 simulants, although its resistance to DIMP (210 min) and DMMP (210 min) is not as good as its resistance to MAL (>24 h) and DBS (> 7 h). Due to its wide availability, duct tape appears to be a useful expedient material to provide at least a temporary seal against permeation by the agents" (Pal et al. 1993, p. 140).

3.2 PLASTIC SHEETING PERMEABILITY

Tests of the permeability of plastic sheeting (polyethylene) challenged with live chemical warfare agents were conducted at the Chemical Defense Establishment in Porton Down, England in 1970 (NATO 1983, p. 133). Agents tested included H and VX, but not GB. Four types of polyethylene of varying thickness were tested: 2.5, 4, 10 and 20 mil (0.0025, 0.004 in., 0.01 in., and 0.02 in.). The results of these tests are shown in Table 1.

Table 1: Permeability of plastic sheeting to liquid agent

	Breakthrough time (h)	
Thickness	VX	H
0.0025	3	0.3
0.004	7	0.4
0.01	30	2
0.02	48	7

Source: NATO 1983, p. 136.

The data shows that at thickness of 10 mil or greater, the plastic sheeting provided a good barrier for withstanding liquid agent challenges, offering better protection against VX than for H. Because the greatest challenge is from a liquid agent, the time to permeate the sheeting will be longer for aerosols and still longer for vapors, but the exact relationship is unknown due to a lack of test data.

In Fig. 1 we plot the data in Table 1 to determine the nature of the relationship between thickness and breakthrough time. The data suggest a somewhat linear relationship, thus allowing some interpolation for various thickness of plastic sheeting. For reference, commercially available sheeting is typically sold at 0.7, 1, 1.2, 1.5, 2, .2.5, 3, 4, 6, and 10 mil. although thicker material is available (up to 100 mil). Plastic painter drop cloths are sold between 0.5 and 2 mil.

4. HOW HAVE THEY PERFORMED IN TESTS OR REAL EVENTS?

Although the "safe room" strategy was used in the many scud missile attacks against Israel in the Gulf War, no chemical agents were released during these attacks. Sheltering has been recommended as a protective action in several chemical releases in the United States and Canada. Some anecdotal information exists about sheltering effectiveness in those events, but no empirical studies of actual effectiveness in a real event have been conducted. Such data would be extremely difficult to capture. Two sets of experiments have been conducted on the effectiveness of in-place sheltering (Rogers et al. 1990; Blewett et al. 1996).

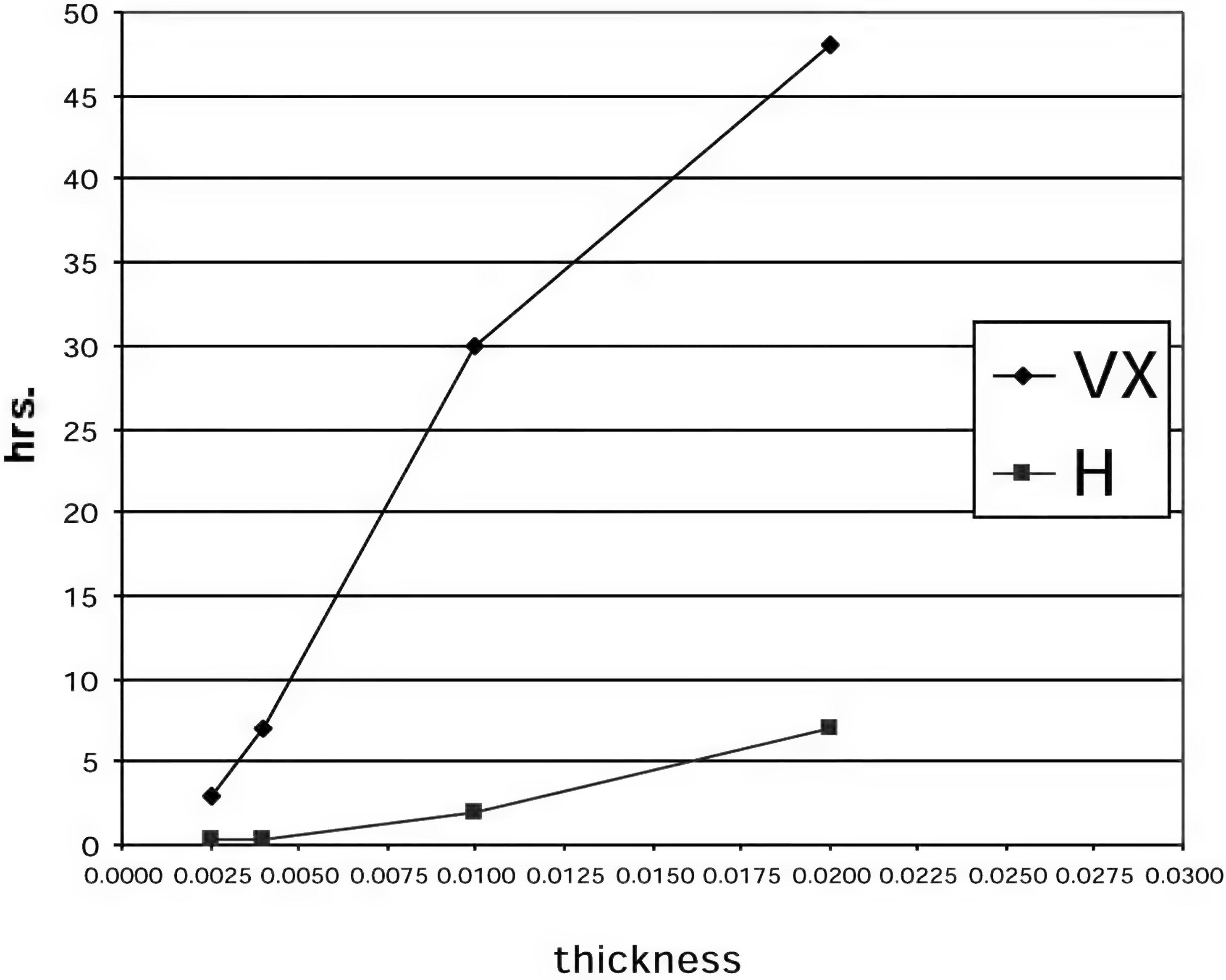

Fig. 1. Breakthrough as a function of the thickness of plastic sheeting.

The results of the two sets of experiments or trials using tracer gas methods provide some insight into the effectiveness of expedient sheltering. These trials were conducted in the vicinity of Oak Ridge, TN., in the late 1980s and Edgewood, MD in the mid 1990's. The Oak Ridge tests involved 12 single-family homes. The trials measured the air exchange for the whole house, the expedient room (mainly bathrooms) with a towel against the door, and the bathroom fully taped and sealed by a household member. Materials used included duct tape, flexible insulation cord, and plastic sheeting. In each test, subjects were given written instructions and checklists, but were left to make the decision how to seal the room.

Infiltration or air exchange is measured by the number of air changes per hour (ach). The average air exchange rate for the houses tested in the Oak Ridge trials was 0.45 ach. The bathrooms with a towel averaged only 0.94 ach. The fully sealed bathrooms averaged

0.33 ach, a reduction of 0.61 ach or 65% (0.61/0.94). One factor not assessed in the study was the air exchanged between the sealed room and the whole house versus the sealed room and the outside. If one assumes that the air exchanged by the room is mostly with the rest of the house, an added protection factor would be achieved because the contaminated air concentrations outside the house are reduced by mixing with air in the whole house and then reduced again in the expedient room. If it is assumed that most of the exchange is between the room and the outside, little added protection beyond that provided by the room would be achieved.

The tests in Edgewood, Maryland, involved 10 residential buildings and 2 mobile homes. Three types of rooms were tested: bathrooms with windows, windowless bathrooms, and walk-in closets. The expedient measures were applied by technicians, and the doors were taped from the outside of the room. A total of 36 trials were performed using different configurations of protection. The results (Table 2) show the air exchange rate for the whole house and for the room in which the expedient measure(s) was applied. The most aggressive strategy (Method 2) proved to be fairly effective, reducing average air exchange rates to between 0.15 and 0.21 ach.

Table 2: Results of Edgewood trials

Room and method	Average house ach	Average room ach
Bathroom—no expedient measures	0.29	0.27
Method 1: Bathroom—wet towel and taped vent	0.28	0.23
Method 2: Bathroom—door taped, plastic sheet on window, wet towel and taped vent	0.32	0.21
Windowless bathroom—no expedient measures	0.37	0.29
Method 1: Windowless bathroom—wet towel and taped vent	0.33	0.29
Method 2: Windowless bathroom—door taped, wet towel and taped vent	0.34	0.15
Walk in closet—no expedient measures	0.39	0.28
Method 1: Walk in closet—wet towel and taped vent	0.44	0.30
Method 2: Walk in closet—door taped, wet towel and taped vent	0.21	0.15

A good way of examining the numbers in the table is to compare the baseline case (door closed with no expedient protection) to the case with the greatest amount of expedient protection (Method 2). For the bathroom, the ach dropped from 0.27 to 0.21 (22%). For the windowless bathroom, the ach dropped from 0.29 to 0.15 (48%). For the closet, the ach dropped from 0.28 to 0.15 (46%).

The results of the two studies are consistent. Both studies showed a reduction of average air exchange rates from expedient protective measures. In some of the specific rooms tested such measures substantially reduced air infiltration into the sealed room when compared to the unsealed room. Infiltration was reduced in one trial by 90% in the

Oak Ridge study and by 57% in Edgewood study. In addition, fairly low air exchanges were achieved in some of the specific expedient room trials (0.11 ach in both studies). The effectiveness of individual trials varied. In the Oak Ridge study, the lowest reduction was 13% and highest air exchange rate was 0.58 ach. In the Edgewood study, the highest air exchange rate for the most aggressive strategy (Method 2) was 0.31 ach. The greater variability in the Oak Ridge data likely results from the variability in the way individuals implemented the taping and sealing, which was more uniform in the Edgewood study because taping was done in a consistent manner by a skilled technician.

5. TIMING OF EXPEDIENT SHELTER

In the ORNL study (Rogers et al. 1990), the time to implement the expedient protection was recorded. Overall times ranged between 3 and 44 min in total, with a mean of 19.8 min. The time to close up the house was relatively short, with a mean of 3.2 min with a range of 1 to 6 min. Times to tape and seal ranged between 2.3 and 38.6 min, with a mean of 16.7 min. These data are shown in Fig. 2.

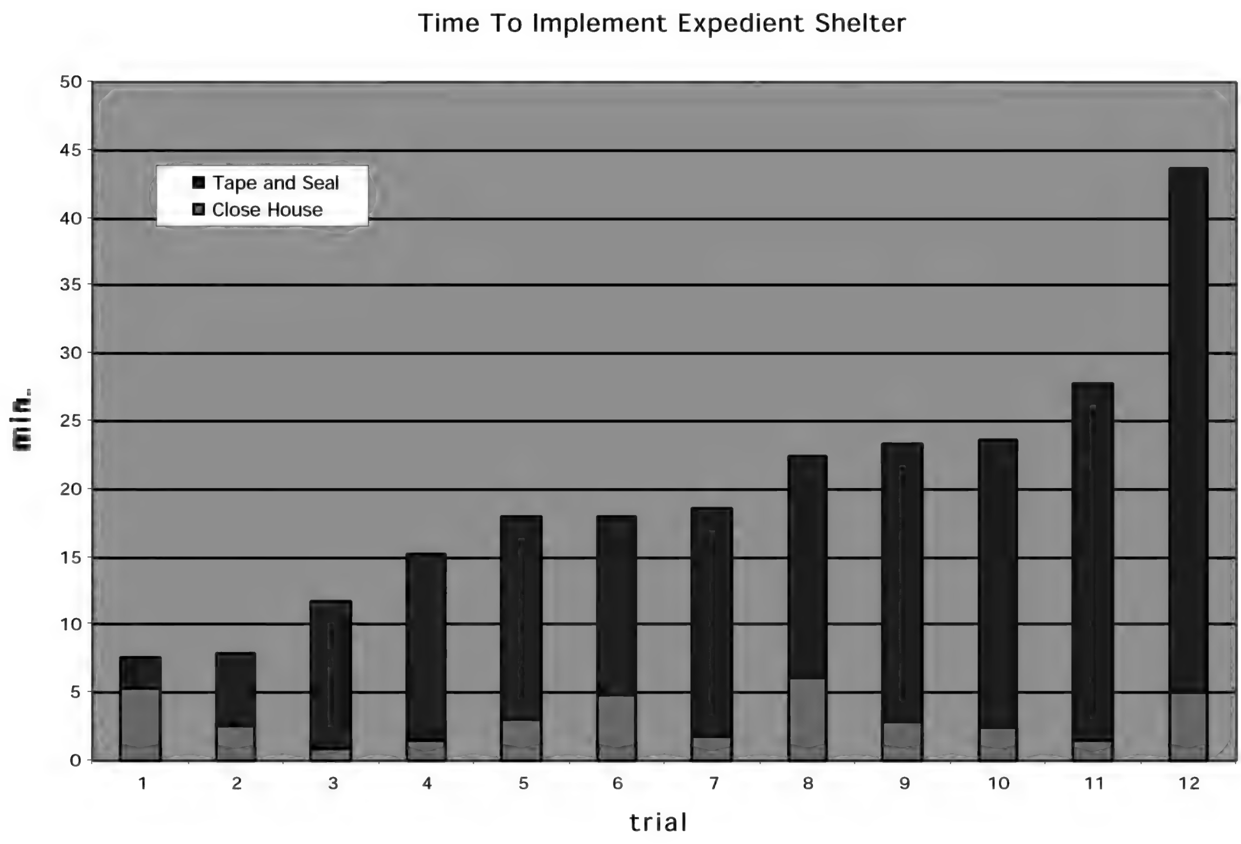

Fig. 2: Expedient shelter trial times.

8. REFERENCES

Blewett, W. K., D. W. Reeves, V. J. Arca, D. P. Fatkin, and B. D. Cannon 1996. *Expedient Sheltering in Place: An Evaluation for the Chemical Stockpile Emergency Preparedness Program*, ERDEC-TR-336, Edgewood Research, Development, and Engineering Center, Aberdeen Proving Ground, Md.

NATO Civil Defense Committee 1983. *NATO Handbook on Standards and Rules for the Protection of the Civil Population Against Chemical Toxic Agents*, AC/23-D/680, 2nd rev.

Pal, T., G.Griffin, G. Miller, A. Watson, M. Doherty, and T. Vo-Dinh. 1993. "Permeation Measurements of Chemical Agent Simulants Through Protective Clothing Materials," *J. Haz. Mat.* **33**:123-141.

Rogers, G. O., A. P. Watson, J. H. Sorensen, R. D. Sharp, and S. A. Carnes. 1990. *Evaluating Protective Actions for Chemical Agent Emergencies*, ORNL-6615, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Sorensen, J. H. 1988. *Evaluation of Warning and Protective Actions Implementation Times for Chemical Weapons Accidents*, ORNL/TM-10437, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Yeshua, I. 1990. *Chemical Warfare: A Family Defense Manual*, Centre for Educational Technology, Ramat Aviv, Israel.

U.S. Department of the Army and Federal Emergency Management Agency. 1996. Planning Guidance for the Chemical Stockpile Emergency Preparedness Program, Washington, D.C.

FINAL REPORT

11 March 1963

Recovery and Decontamination Measures after Biological and Chemical Attack

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

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by

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1079 Wisconsin Avenue, N.W.
Washington 7, D. C.

To plan for countermeasures against any weapons one must understand the problem—the nature, the potentials, and the limitations. This research project and the resultant final report were intended to bring together current information most applicable to civil defense. It was particularly intended for those who are responsible for planning preparatory, reclamation and countermeasures effort to minimize the damage from a BW/CW attack.

William J. Lacy
Project Coordinator
Postattack Research

Decontaminants

An important class of decontaminants comprises the common substances or natural influences such as time, air, earth, water, and fire.

Natural Effects

Biological agents are living organisms and tend to die off with time unless they are in a favorable environment with moisture, food, warmth, and other factors necessary for their survival. In addition, most biological organisms are very sensitive to the conditions of temperature and humidity -- and, particularly to the ultra-violet portion of sunlight. Adverse exposure to the elements -- air, sunlight, high temperature, low humidity -- is effective, in fact, against all biological agents except the spore forms of bacterial organisms.

It is generally assumed that in the vegetative form bacteria (as contrasted to the spore form) can persist for less than two hours during daytime and about eighteen hours at night. Since these short-lived bacteria are the most probable agents, outdoor decontamination is usually not called for unless the agent has been identified, either by laboratory tests or by the character of the disease, as one which forms spores or is otherwise known to be persistent.

The persistent, low-volatile, agents such as the liquid nerve agents (V-agents) and the blister gases present the principal chemical decontamination problem. Even these evaporate in time. The speed of evaporation and dissipation is enhanced by higher temperatures and wind. Thus, if it is possible to avoid the area or the use of contaminated objects for a reasonable length of time, decontamination may be unnecessary. Such periods might run from hours to a few days, depending on the degree of contamination and weather conditions. In cold weather the agents will persist for longer periods.

Water

Next to weathering, the most important natural decontaminant is water, used either to remove the agent, with or without soap or detergents to assist, or by boiling. One caution -- water used to wash away contamination becomes contaminated and must be disposed of accordingly. Boiling destroys most chemical agents and all biological agents. When it is feasible, boiling is one of the most generally desirable methods -- particularly for household use by individuals.

Earth and fire, the other natural decontaminants, would have relatively little application in civil defense BW/CW decontamination operations. Earth may be used to cover contamination temporarily to keep it out of contact with people while natural processes either dissipate or destroy the agent. This involves substantial effort with bulldozers and earth-moving equipment and usually is neither practical or necessary.

Chemical Decontaminants

These are preferred when they are available. Chemical decontaminants fall in two classes -- those which destroy or neutralize the agents, and those which simply assist in their removal.

The principal decontaminants which destroy or neutralize are:

- Chlorine-containing materials, such as calcium hypochlorite (HTH) and sodium hypochlorite solutions. Many household disinfectants available under various brand names -- Clorox, Purex, etc. -- are sodium hypochlorite solutions.
- Alkalies, such as caustic soda (lye) and sodium carbonate (washing soda, or soda ash).

The chlorine-containing materials, in proper concentrations, are effective against both biological and chemical agents. As solutions they are used to decontaminate surfaces, as in washing off sealed food containers; for decontaminating cotton fabrics by soaking or addition during the washing process; and for sterilizing water. Hypochlorite solutions have the disadvantage of corroding metals and so must be rinsed off thoroughly.

The hypochlorites -- calcium and sodium -- are the preferred decontaminants for blister gases and liquid nerve agents. For most such applications they are used as solutions but for vertical surfaces or porous surfaces a "whitewash" of calcium hypochlorite (HTH), hydrated lime, and water (called a "slurry") is more effective

Appraisal of Biological and Chemical Warfare Protection in the U.S. Field Army. Booz, Allen Applied Research, Inc., June 1961. AD 329 113, (SECRET).

Area-Coverage Capabilities of Bacteriological and Chemical Weapons (U). Tamplin, A.R., Rand Corporation, April 1962. AD 329 207, (SECRET).

Biological Decontamination. Asher, T.M., Naval Biological Laboratory, February 1954. AD 72 485, (SECRET).

Biological Problems Attendant Upon the Application of Bacteriological and Chemical Agents in Limited War (U). Tamplin, A.R., Rand Corporation, RM-2677, June 1961. AD 324 462, (SECRET).

Chemical and Biological Weapons Employment. Department of the Army Field Manual, FM 3-10, February 1962.

Community Reaction to an Accidental Chlorine Exposure - Task Sirocco. Segaloff, Louis, University of Pennsylvania, November 1961. AD 269 681.

Decontamination of Water Contaminated with VX. Lindsten, Don C. and Bauer, Virginia E., U.S. Army Engineer Research and Development Laboratories, Research Report 1630-RR, May 1960. AD 239 310.

Effects of Cooking and Baking Processes on the Sterilization of Food Contaminated with Bacterial Spores. Commissary Research Division, U.S. Naval Supply Research and Development Facility, Final Report Navy Project NT 002 024 (CR 53-89), 1953.

Evaluation of Standard and Modified Laundering Procedures as BW Decontamination Methods. Portner, Dorothy M., Mayo, Elizabeth C. and Surkiewicz, Bernard F., Biological Warfare Laboratories, Technical Memorandum 1-2, March 1959. AD 252 270L.

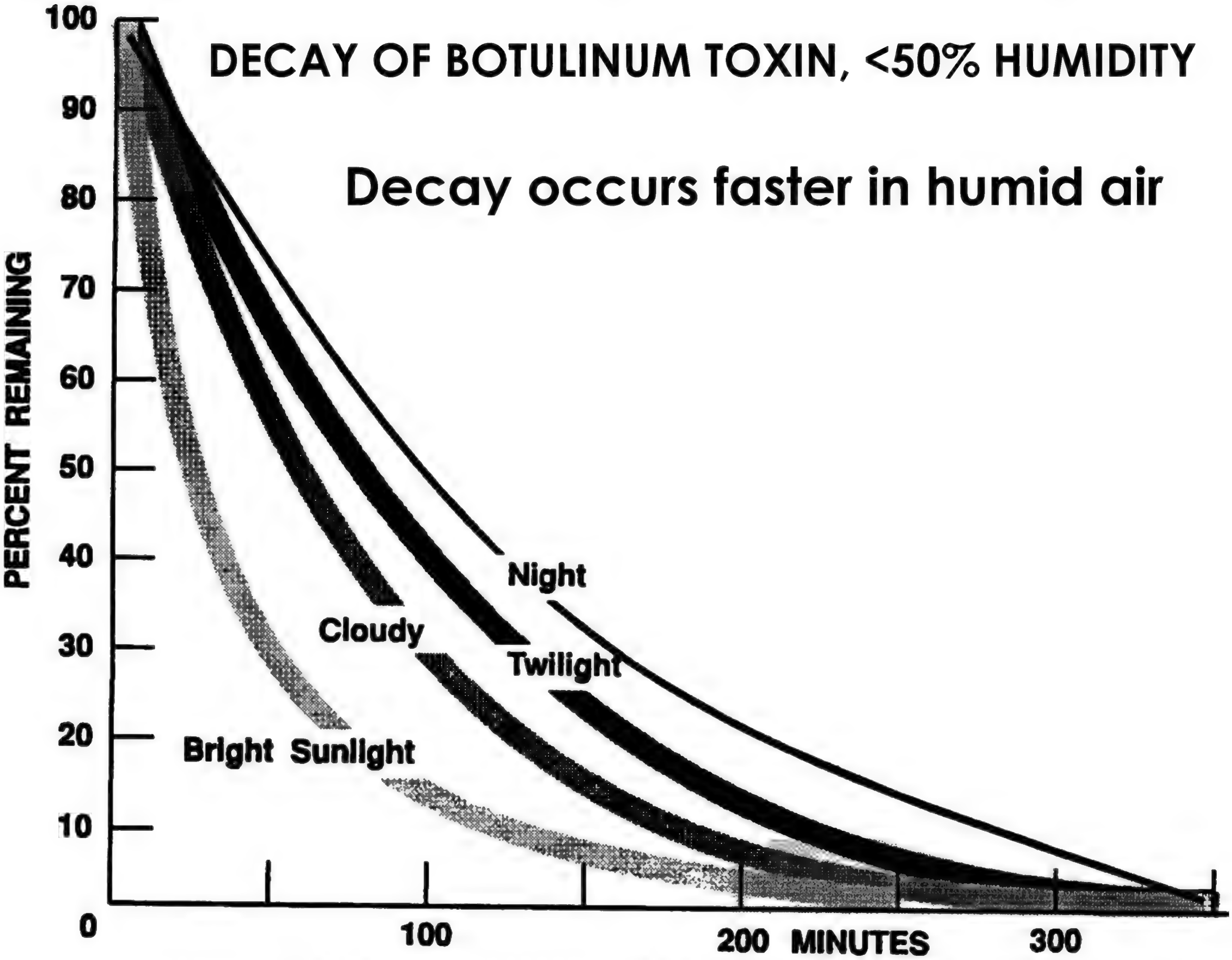
Field Purification of Water Contaminated by G Agents. Chemical Corps Medical Division Report No. 220, 1949. AD 212 449.

Field Tests of Protective Clothing Exposed to BW Aerosols. Chemical Corps Biological Laboratories, Special Report No. 112, August 1949.

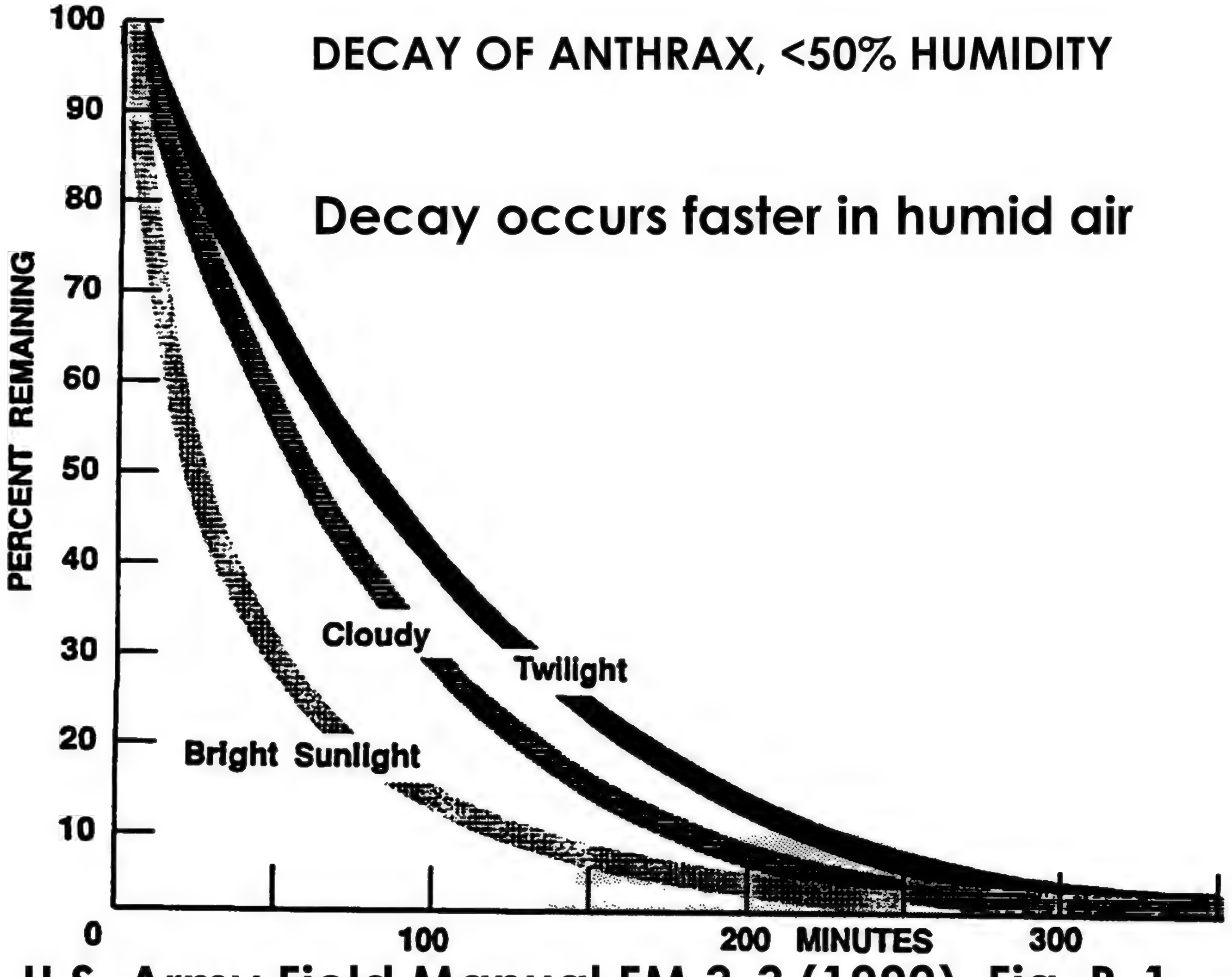
Possible Applications of Bacteriological Warfare to Public Water Supplies. Maloney, John R., Office of Naval Research, November 1959. AD 69 721, (CONFIDENTIAL).

Some Indications of Soviet Views on the Strategic Employment of CW/BW (U). Gouré, Leon, Rand Corporation, RM-2725, March 1961. (SECRET).

Studies on Insect Control (U). U.S. Army Engineer Research and Development Laboratories, Research Report 1656-RR, October 1960. AD 321 975, (CONFIDENTIAL).



U.S. Army Field Manual FM 3-3 (1992), Fig. B-3.



U.S. Army Field Manual FM 3-3 (1992), Fig. B-1.

- Basic decontamination procedures are generally the same no matter what the agent. Thorough scrubbing with large amounts of warm soapy water or a mixture of 10 parts water to 1 part bleach (10:1) will greatly reduce the possibility of absorbing an agent through the skin.

Sealing a Room

- Close all windows, doors, and shutters.
- Seal all cracks around window and door frames with wide tape.
- Cover windows and exterior doors with plastic sheets (6 mil minimum) and seal with pressure- sensitive adhesive tape. (This provides a second barrier should the window break or leak).
- Seal all openings in windows and doors (including keyholes) and any cracks with cotton wool or wet rags and duct tape. A water-soaked cloth should be used to seal gaps under doors.
- Shut down all window and central air and heating units.

Suggested Safehaven Equipment

- Protective equipment—biological/chemical rated gas masks, if available; waterproof clothing including long-sleeved shirts, long pants, raincoats, boots, and rubber gloves.
- Food and water—a 3-day supply.
- Emergency equipment—flashlights, battery-operated radio, extra batteries, can or bottle opener, knife and scissors, first aid kit, fire extinguisher, etc.
- Most chemical and biological agents that present an inhalation hazard will break down fairly rapidly when exposed to the sun, diluted with water, or dissipated in high winds.

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Responding to a Biological or Chemical Threat IN THE UNITED STATES

In 1995, the Aum Shinrikyo, a Japanese religious cult, launched a large-scale chemical attack on the Tokyo subway system. The attack focused on four stations using Sarin gas, a potent chemical warfare nerve agent. Twelve people were killed but the attack fell far short of the apparent objective to inflict thousands of casualties. Subsequent investigation by authorities revealed that the cult had previously conducted several unsuccessful attacks against a variety of targets using other chemical agents and the biological agents botulism toxin and anthrax.

More recently, the incidents of anthrax contamination in the United States served to illustrate the viability of this type of terrorist threat. Again, the attacks fell short of mass casualties, but some deaths did occur and the fear and disruption caused by a few positive anthrax findings were crippling. The U.S. Government continues working to meet the potential consequences of such attacks.

ORNL-6615

EVALUATING PROTECTIVE ACTIONS FOR CHEMICAL AGENT EMERGENCIES

by

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APPENDIX G
INSTRUCTIONS FOR IMPLEMENTING EXPEDIENT SHELTER IN CHEMICAL EMERGENCIES

Entering your dwelling or other buildings and following a few simple procedures can reduce exposure to released toxic chemical. These instructions can help you implement a series of actions to increase your protection. The series includes six basic steps:

1. preparing your dwelling to provide protection,
2. selecting an appropriate room within your dwelling to provide maximum shelter,
3. assembling the necessary materials needed to complete the procedures,
4. sealing a room within the dwelling to provide additional protection,
5. remaining in the shelter until notified that the hazard has passed, and
6. vacating the shelter upon plume passage.

Because each house is in some ways unique, you may need to adapt these procedures to your particular home. These instructions order the activities in terms of what is most important in obtaining maximum protection. Therefore, we recommend that you follow these steps in sequence wherever possible. Time is critically important to ensure adequate protection, so implement each step as quickly as you can without making mistakes and continue to the next step as soon as possible.

G.1. Preparing Your Dwelling

The objective is to prepare your dwelling to provide the maximum reduction of airflow from outside to inside. These preliminary steps also provide some protection while you carry out the procedures.

1a. Go or stay indoors.
1b. Close all exterior doors and windows (close storm windows if this can be done quickly). Don't forget garage doors in integral or attached garages as well as doors normally left open for ventilation.
1c. Close all interior doors.
1d. Turn off central heat/air conditioning fans, ceiling fans, kitchen hood fans, and circulating fans.

G.2. Selecting the Appropriate Room

The objective is to select the room that is best suited to reducing overall air infiltration while having at least 10 square feet of floor area per person. Under hot and humid conditions more space is advisable to avoid conditions that might lead to heat prostration within the shelter. Moreover, room air conditioners that recirculate internal air may be used to create more comfortable shelter conditions. For example a 5×8 foot room has 40 ft^2, which would be appropriate for sheltering up to 4 people. This step can be completed in advance. If you have already preselected the room to provide maximum shelter, skip to Sect. G.3 below.

2a. The best room is a relatively small, has no outside walls, and is on the ground floor.
2b. If 2a is not available; select a small room with no windows.
2c. If 2a and 2b are not available: select the room with the smallest number of windows and doors.
2d. Avoid rooms with window air conditioners, windows that leak, vents to outside such as automatic dryer vents, and circulation vents.
2e. <u>Do not select rooms with exhaust vents that automatically start when the light is turned on</u>. These exhaust fans force external air into the room.
2f. If all the above elements are the same for two rooms, choose the room that is free of plumbing fixtures, because such fixtures increase the potential airflow and will require sealing as described in Sect. G.4 below.

G.3. Assembling Materials and Resources

This stage of the procedures is designed to collect all the needed materials to reduce the airflow as much as possible in the room you selected in Sect. G.2 above. This step can be performed ahead of time. Place the following materials in the selected room.

3a. the expedient shelter kit provided;
3b. verify that the kit still has the tape, plastic sheet, scissors, clay, and screwdriver;
3c. obtain a large towel (at least bath-towel size);
3d. a ladder, stool, or chair if required to seal any ceiling vents or the tops of windows and doors;
3e. a radio or television or other communication device (preferably portable) to let you to know when the plume has passed so you can exit at an appropriate time; and
3f. if the selected room does not have plumbing, drinking water and sanitary facilities (a covered bucket or other vessel containing approximately 1 cup of chlorine bleach).

G.4. Taping and Sealing

This set of procedures is designed to identify and seal the major sources of airflow between the room you have selected and the rest of the house, as well as restrict the flow of any toxic chemical that may be outside. These steps are sequenced to eliminate larger sources of air exchange first, so they should be implemented in the order listed whenever possible.

4a. Assemble people to be protected in the selected room and close the door. If windows were not closed as instructed in Sect. G.1 above, do so now.

4b. Jam the towel under the entire width of the door, sealing the whole area between the bottom of the door and the floor.

4c. VENTS: If there are no vents, skip to step 4d below. Locate any vents associated with the heating system, fan vents which are sometimes located in bathrooms, or vents to other rooms or to the outside such as dryer vents. Then, tape over small vents repeatedly, overlapping the tape to form a complete seal. For large vents, cut a piece of plastic sheeting large enough to cover the vent, place it over the vent, and tape the plastic loosely in place at the corners. Tape the plastic along each edge to ensure a complete seal. Repeat for each vent in the room.

4d. WINDOWS: If there are no windows, skip to step 4e below. If there are any broken or cracked windows, apply tape or cling-wrap over glass. Locate all leak points (any joints in the window frame, where movable parts of the frame come together), apply cling-wrap to each leak point. Then, cut a piece of plastic sheeting large enough to cover window and window frame, place it over the window and frame, and tape the plastic loosely in place at the corners. Tape the plastic along each edge to ensure a complete seal.

4e. Before you complete the seal on the door, check all supplies to ensure that you have enough material to completely seal the door. Do not open the door unless you clearly have inadequate materials to complete the seal; breaking the door seal will substantially reduce the protection provided by the refuge.

4f. DOOR: Tape along each edge of the door to seal off airflow, beginning with the parts you can reach from the floor and proceeding to the upper parts that may require the use of a ladder, stool, or chair. Place and tape cling-wrap over each hinge and the door handle.

4g. PLUMBING FIXTURES: If there are no plumbing fixtures, skip to step 4h below. Use putty or clay around all pipes that penetrate walls, ceiling, or floor (both intake and drainage pipes). To apply clay or putty, pull back the pipes decorative sealing ring (use screwdriver if necessary), wrap enough clay or putty around the pipe to fill any gaps between the wall and the pipe, and reset the decorative ring in clay by pressing the ring firmly against wall. Repeat for all pipe entry and exit points.

4h. CABINETS: If there are no built-in cabinets such as sink cabinets, linen closets, or medicine cabinets, skip to step 4i below. Close the cabinet doors and tape them closed according to the procedures described for doors in step 4f above. Note that, because cabinet hinges and handles are smaller than those on doors, tape will probably cover these areas adequately. Then, tape or use cling-wrap along all joints where the cabinet meets the wall. Pay particular attention to kickplates below cabinets, by checking the underside for holes and gaps. Smaller gaps may need to be plugged with clay.

4i. ELECTRICAL FIXTURES: Locate all electrical fixtures, including outlets, switch boxes, and lights. If a light is recessed or if it cannot be sealed without turning it off, it will have to remain unsealed because covering a light without turning it off may start a fire. Put tape over the outlet boxes, and use cling-wrap or tape to cover all switch boxes. Put cling-wrap over light fixtures not in use. (Some light fixtures contain fans that run continuously with the light in the room. These fans should be turned off as early as practical; if they cannot be turned off, a different room should be selected as instructed in Sect. G.2 above.)

4j. CHECKING YOUR WORK: After, you have completed the procedures to seal the room you have selected, check each area you sealed by slowly passing your hand in front of all potential leak areas. If you can feel air flowing, try to seal it better. We do not recommend that you remove any previous seals, but you may want to add plastic sheeting over sealed areas or tape them more securely.

G.5. Remaining in Shelter

The objective of this stage is to relax as much as possible and wait to be notified of the appropriate time to exit the shelter.

5a. Shelter occupants should be as comfortable as possible; they should stand or move around as little as possible.
5b. Remain calm and relax; doing so adds additional protection by reducing your respiration rate.
5c. Turn on communication device so you can be contacted when it is safe to exit the shelter.
5d. Ask each occupant to periodically check for airflows near them. If any are discovered, seal them by following the above procedures.
5e. Wait for notification of plume passage.

G.6. Vacate Shelter

The objective of this step is to exit the shelter when the plume passes by and to avoid any further cumulative exposure.

6a. Put on protective clothing.
6b. Open all windows and doors.
6c. Evacuate to reception center for medical evaluation and decontamination.

EXPEDIENT SHELTER INSTRUCTION CHECKLIST

1. Prepare your dwelling to provide protection.

1a. Go or stay indoors.
1b. Close all exterior doors and windows.
1c. Close all interior doors.
1d. Turn off fans.

2. Select an appropriate room within your dwelling to provide maximum shelter, <u>having at least 10 square feet of floor area per person</u>.

2a. Choose a relatively small room with no outside walls on the ground floor.
2b. If not available: select a small room with no windows.
2c. If not available: select the room with the fewest windows and doors.
2d. Avoid rooms with window air conditioners, windows that leak, vents to the outside, and circulation vents whenever possible.
2e. Avoid rooms with plumbing fixtures whenever possible.

3. Assemble the necessary materials.

3a. Use the expedient shelter kit provided;
3b. Verify that its contents are complete;
3c. Large towel of at least bath-towel size;
3d. Ladder, stool, or chair if necessary;
3e. Radio, television, or other communication device;
3f. Drinking water and covered container with chlorine bleach for sanitary purposes.

4. Seal a room in the dwelling to provide additional protection.

4a. Enter the selected room and close the door.
4b. Jam the towel under the door.
4c. Seal vents.
4d. Seal windows.
4e. Check all supplies; replace if necessary.
4f. Seal door.
4g. Seal plumbing.
4h. Seal cabinets.
4i. Seal electrical fixtures.
4j. Check you work; reseal where necessary.

5. Remain in the shelter until notified that the plume has passed.

5a. Get as comfortable as possible.
5b. Remain calm, relax, and stay immobile.
5c. Turn on communication device.
5d. Periodically check for airflows in the shelter.
5e. Wait for notification of plume passage.

6. Vacate shelter.

6a. Don protective clothing.
6b. Open all windows and doors.
6c. Evacuate.

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Energy Division

Expedient Respiratory and Physical Protection: Does a Wet Towel Work to Prevent Chemical Warfare Agent Vapor Infiltration?

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1. INTRODUCTION

Several public information efforts in the Chemical Stockpile Emergency Preparedness Program (CSEPP) advocate the use of wet towels to (1) seal a door jam against the infiltration of chemical vapors and (2) provide expedient respiratory protection.

A wet towel has been a common respiratory protection practice for fires to reduce inhalation of soot and smoke, but will this strategy protect against chemical vapors? Using a wet towel to reduce infiltration of chemicals into a room by sealing the gap between the floor and the door is frequently cited in the shelter-in-place (SIP) literature (see Blewett et al. 1996).

The purpose of this paper is to examine the effectiveness of such measures to reduce exposure to vapors from chemical warfare agents. This evaluation includes an examination of the physical and the psychological effectiveness of these measures. Little research has been conducted to examine the effectiveness of expedient protection against chemical vapors and aerosols. More is known about the penetration of aerosols than vapor. In this paper, we summarize the research to date and offer several recommendations for CSEPP.

2. PREVIOUS RESEARCH ON EXPEDIENT PROTECTION

The first documented research on expedient respiratory protection was conducted by Guyton et. al. (1959). They performed a series of tests to determine whether common household items provided respiratory protection against a release of radiological or biological aerosols. The materials they tested included

- a man's cotton handkerchief,
- a women's cotton handkerchief,
- cotton clothing material,
- muslin bed sheet,
- cotton shirt,
- rayon slip,
- cotton terry bath towel, and
- toilet paper.

In total, 18 variations of the 8 materials were tested. The tests performed used human subjects who inhaled *B. globigii* (a bacteria aerosol) through the various materials into a mouthpiece collector. The results of the testing indicated that 5 of the variations had filtration efficiency of greater than 85%. These included a folded (16 and 8 thickness) or crumpled handkerchief, 3 thickness of toilet paper, and a bath towel folded in half. Tests were performed on wetted items, but the efficiency was lower than for dry items. In addition, only the bath towel was feasible to breath through when wet. No testing for vapor protection was performed.

A series of experiments was performed by the Harvard School of Public Health in the early 1980's (Cooper, Hinds, and Price 1981; 1983; Cooper et al. 1983a,b; Price, Cooper, and Yee 1985). These efforts sought to build on the work of Guyten et al. by examining the penetration of expedient materials by particle size and by examining penetration by vapors. Materials similar to those in the earlier studies were used; but instead of human subjects, several test chambers were designed. Mineral oil was used for the aerosol tests and methyl iodide and iodine were used in the vapor tests. Methyl iodide is a difficult vapor to capture, while iodine, a highly reactive gas, was chosen because it is readily removed by wet filtration, thus setting the upper boundary for effectiveness against a gas.

The first set of tests examined the effectiveness of the materials in filtering the aerosols and vapors. For aerosols, the reductions by a factor of 30 were achieved with the dry materials across the range of aerosol sizes. Reductions by a factor of five were achieved with wet materials. No filtration was achieved with dry materials for both vapors. As predicted, wet materials had no effectiveness for methyl iodide but were effective in filtration of iodine vapors (60 % filtration) (Cooper, Hinds, and Price 1981; 1983).

Additional experiments were performed using a manikin to evaluate aerosol leakage around the protective materials assessed in the first experiments. These tests showed that the leakage rates around the edges of the expedient materials (in addition to the leakage of the materials), ranged as high as 63%. The study concluded that holding expedient materials over the face would not provide significant protection against aerosols due to the leakage problem. The study also concluded that some material, such as a panty hose, was needed to secure the expedient protective materials around the mouth and nose in order to minimize leakage (Cooper et al. 1983a,b). Although vapors were not included in this study, it is reasonable to assume that leakage around the perimeters of the materials would also be problematic for vapors.

Additional tests were performed with aerosols in the extremely small particle size range (Price, Cooper, and Yee 1985). These tests, as with the other aerosol tests, are not relevant for civilian protection in CSEPP SIP actions because of the extremely low likelihood of aerosol contamination off-post.

A major concern in all studies was the ability to inhale through the expedient materials. This proved problematic for all wet materials except for wet toweling. For the thick dry materials, such as the folded handkerchief—which was the most effective filter, breathing comfortably would be possible for only short periods of time.

Additional work on the effectiveness of expedient protection against chemical warfare agent simulants was conducted as part of a study on chemical protective clothing materials (Pal et al. 1993). Materials included a variety of chemical-resistant fabrics and duct tape. The materials were subject to liquid challenges by the simulants DIMP (GB simulant), DMMP (VX simulant), MAL (organoposphorous pesticide), and DBS (mustard simulant). The study concluded that "Duct tape exhibits reasonable resistance to permeation by the 4 simulants, although its resistance to DIMP (210 min) and DMMP (210 min) is not as good as its resistance to MAL (>24 h) and DBS (> 7 h). Due to its wide availability, duct tape appears to be a useful expedient material to provide at least a temporary seal against permeation by the agents" (Pal et al. 1993, p. 140).

3. ADDITIONAL CONSIDERATIONS

Expedient respiratory protection may have social-psychological benefits as well as problems that need to be examined as well.

Problems

Expedient respiratory protection can cause or exacerbate problems by

- deterring oral communications among a family in a sheltered room and communications are very important in a SIP situation,
- deterring taping a room if people attempt to use expedient respiratory protection from the onset of SIP,
- being an additional resource for a SIP kit or materials that would need to be located at the time of a SIP warning,
- hampering driving ability during evacuation because of impairment of hand use and possible visual difficulty, and
- causing hyperventilation in some people with a tendency to be claustrophobic about impediments to breathing.

Benefits

Expedient respiratory protection can also

- have a placebo effect, making people believe they are safe while they are in a SIP and
- reinforcing the concept of proactive protection during SIP.

Overall, it appears that the non-physical benefits of expedient respiratory protection do not exceed the potential problems. However, it will be important to communicate to the public that expedient respiratory protection is beneficial in other emergency situations (such as a fire or for volcanic ash).

4. RECOMMENDATIONS FOR CSEPP

Respiratory protection for civilians has never been considered a viable option for population protection in the CSEPP. Problems of storage, ability to effectively don respirators, and questionable fit have been primary factors in rejecting this option. Expedient respiratory protection seems to offer little benefit for population protection.

Because chemical warfare agent vapors are not reactive with water—or, in some cases, not very soluble, even if easily hydrolyzed (Munro et al. 1999)—it is unlikely that wetted towels will provide significant respiratory protection while a person is sheltering in place. In no case would it be recommended that people attempt to evacuate through a vapor plume with or without expedient respiratory protection. Because of the physical ineffectiveness of the practice and the fact that the social-psychological benefits do not outweigh the social-psychological problems, we recommend that expedient respiratory protection should not be used in CSEPP protective action strategies.

Furthermore, we believe that using wet towels as a vapor barrier at the bottom of a door should be discouraged in favor of using duct tape to seal the bottom of doors. A wet towel provides no vapor filtration; and while it will reduce infiltration, its effectiveness in doing so is not known. A towel wetted with a 0.5% solution of hypochlorite (a 1:9 dilution of household bleach) may provide some protection. A hypochlorite solution is an effective decontaminant for nerve agent vapors and would provide dual protection, both physical and chemical (Munro et al. 1990). Taping the bottom of the door will still likely provide greater infiltration reduction and is recommended as the current method for use in SIP for CSEPP.

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6. REFERENCES

Blewett, W. K., D. W. Reeves, V. J. Arca, D. P. Fatkin, and B. D. Cannon 1996. *Expedient Sheltering in Place: An Evaluation for the Chemical Stockpile Emergency Preparedness Program*, ERDEC-TR-336, Edgewood Research, Development, and Engineering Center, Aberdeen Proving Ground, Md.

Cooper, D. W., W. C. Hinds, and J. M. Price 1981. *Expedient Methods of Respiratory Protection,* NUREG/CR-2272, Sandia National Laboratory, Albuquerque, N.M

Cooper, D. W., W. C. Hinds, and J. M. Price 1983. "Emergency Respiratory Protection with Common Materials," *Am. Ind. Hyg. Assoc. J.* **44**(1):1-6.

Cooper, D.W., W. C. Hinds, and J. M. Price, R. Weker, and H. S. Yee 1983a. "Common Materials for Emergency Respiratory Protection: Leakage Tests with a Manikin," *Am. Ind. Hyg. Assoc. J.* **44**(10):720-26.

Cooper, D. W., W. C. Hinds, J. M. Price, R. Weker, and H. S. Yee 1983b. "Expedient Methods of Respiratory Protection II: Leakage Tests," NUREG/CR-2958, Sandia National Laboratory, Albuquerque, N.M.

Guyton, N. G., H. M. Decker, and G. T. Anton 1959. "Emergency Respiratory Protection Against Radiological and Biological Aerosols," *A.M.A. Arch. Ind. Hlth.* **20**(Aug.):91-95.

Munro, N. B., A. P.Watson, K. R. Ambrose, and G. D. Griffin 1990. "Treating Exposure to Chemical Warfare Agents: Implications for Health Care Providers and Community Emergency Planning," *Env. Hlth. Persp.* **89**: 205-15.

Munro, N. B., S. S. Talmage, G. D. Griffin, L. C. Waters, A. P. Watson, J. F. King, and V. Hauschild 1999. "The Sources, Fate, and Toxicity of Chemical Agent Degradation Products," *Env. Hlth. Persp.* **107**:933-974.

Pal, T., G. D. Griffin, G. Miller, A.P. Watson, M. L. Doherty, and T. Vo-Dinh 1993. "Permeation Measurements of Chemical Agent Simulants Through Protective Clothing Materials," *J. Haz. Mat.* **33**:123-41.

Price, John M., Douglas W. Cooper, and H. S. Yee 1985. "Expedient Methods of Respiratory Protection III: Submicron Particle Tests and Summary of Quality Factors," NUREG/CR-3537, Sandia National Laboratory, Albuquerque, N.M.